LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-TR-498872

SUMMARY OF INTERNATIONAL WASTE MANAGEMENT PROGRAMS

H. R. Greenberg, J. A. Blink, W. G. Halsey, M. Sutton

September 12, 2011

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Used Fuel Disposition Campaign

Technical Bases / Lessons Learned
(Work Package FTLL11UF0328)

Level 4 Milestone (M4): M41UF032802
(LLNL input to SNL L3 Milestone: System-Wide Integration and Site Selection Concepts for Future Disposition Options for HLW)

SUMMARY OF INTERNATIONAL WASTE MANAGEMENT PROGRAMS

Lawrence Livermore National Laboratory

Harris R. Greenberg, James A. Blink, William G. Halsey, and Mark Sutton

AUGUST 2011

LLNL-TR-498872

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Summary of International Waste Management Programs
LLNL Input to SNL L3 MS: System-Wide Integration and Site Selection Concepts for Future Disposition Options for HLW

Contents

List of Tables

List of Figures

Acronyms

ABWR	Advanced Boiling Water Reactor
AEC	Atomic Energy Commission (United States)
AEC	Atomic Energy Council (Taiwan)
AECL	Atomic Energy of Canada Limited
AEOI	Atomic Energy Organization of Iran
AGR	Advanced Gas Reactor
ANDRA	National Radioactive Waste Management Agency (France)
ASN	Nuclear Safety Authority (France)
BARC	Bhabha Atomic Research Centre (India)
BFS	Office for Radiation Protection (Germany)
BMU	Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (Germany)
BRC	Blue Ribbon Commission on America’s Nuclear Future
BWR	Boiling Water Reactor
CANDU	A heavy-water natural uranium reactor designed by Canada
CARE	Cavern Retrievable (Japan)
CEA	Atomic Energy Commission (France)
CIGEO	Industrial Centre for Geological Disposal (France)
CLAB	An interim repository for used fuel (Sweden)
CLI	Local Information Committees (France)
CNE	National Review Board (France)
CNEA	National Atomic Energy Commission (Argentina)
CNNC	Chinese National Nuclear Corporation
CNSC	Canadian Nuclear Safety Commission
COEX	Co-Extraction process
CORA	Committee on Radioactive Waste Disposal (Netherlands)
CoRWM	Committee on Radioactive Waste Management (United Kingdom)
COVRA	Central Organization for Radioactive Waste (Netherlands)
CSN	Nuclear Safety Council (Spain)
CSTFA	Morvilliers facility (France)
DBE	German Service Company for the Construction and Operation of Waste Repositories
DOE	Department of Energy
ENRESA	A state-owned company in charge of nuclear waste (Spain)
EPRI	Electric Power Research Institute
EBRD	European Bank for Reconstruction and Development
EC	European Commission
EUR	Euro (unit of currency)
EURIDICE	European underground research infrastructure for disposal of radioactive waste in a clay environment (Belgium)
FANC	Federal Agency for Nuclear Control (Belgium)
FBR	Fast Neutron Reactor
FCT	Fuel Cycle Technology

FEPC	Federation of Electric Power Companies (Japan)
FY	Fiscal Year
GACID	Global Actinide Cycle International Demonstration (Japan)
GANEY	Group extraction of actinides
GCHR	Gas Cooled Heavy Water Reactor
GCR	Gas Cooled Reactor
GDF	Geological disposal facility (UK)
GNEP	Global Nuclear Energy partnership
GWe	Gigawatts electric
HADES	High-activity disposal experimental site (Belgium)
HEU	High Enriched Uranium
HLW	High Level Waste
HTR	High Temperature Reactor
IAEA	International Atomic Energy Association
ICAO	International Civil Aviation Organization
ICSRM	Industrial Complex for Radwaste Management (Ukraine)
ILW	Intermediate-level wastes
IMO	International Maritime Organization
JAEA	Japanese Atomic Energy Agency
JAERI	Japan Atomic Energy Research Institute
J-MOX	A MOX fuel fabrication facility in Rokkasho, Japan
JPDR	Japan Power Demonstration Reactor
KAERI	Korea Atomic Energy Research Institute
KHNP	A hydro and nuclear energy utility (South Korea)
KNFC	Korea Nuclear Fuel Company (South Korea)
KRWM	Korea Radioactive Waste Management Co. Ltd
KURT	KAERI Underground Research Tunnel
LILW	Low and intermediate-level wastes
LILW_LL	IAEA definition for long-lived low and intermediate-level
LILW_SL	IAEA definition for short-lived low and intermediate-level SL
LLNL	Lawrence Livermore National Laboratory
LLW	Low-level wastes
LWGR/EGP	A graphite moderated boiling water reactor
LWR	Light Water Reactor
MOX	Mixed Oxide fuel
MTU	Metric Tons of Uranium
NAGRA	National Cooperative for the Disposal of Radioactive Waste (Switzerland)
NDA	Nuclear Decommissioning Authority (United Kingdom)
NE	DOE – Nuclear Energy
NEA	Nuclear Energy Agency (Organization for Economic Cooperation and Development)
Nesca	South African Nuclear Energy Corporation
NETEC	Nuclear Environment Technology Institute (South Korea)
NEWMDB	Net-Enabled Waste Management Database (maintained by IAEA)
NISA	Nuclear & Industrial Safety Agency (Japan)
NRC	Nuclear Regulatory Commission (United States)

NWF	Nuclear Waste Fund (United States)
NUMO	Nuclear Waste Management Organization (Japan)
NWMO	Nuclear Waste Management Organization (Canada)
NWPA	Nuclear Waste Policy Act (United States)
NWPAA	Nuclear Waste Policy Amendments Act (United States)
NWTRB	Nuclear Waste Technical Review Board
ONDRAF/ NIRAS	Belgian National Agency for Radioactive Waste and Fissile Materials
OPECST	Parliamentary Office for the Evaluation of Science and Technology Options (France)
OPG	Ontario Power Generation (Canada)
PHWR	Pressurized Heavy Water Reactor
PRACLAY	Preliminary demonstration test for clay disposal of highly radioactive waste (Belgium)
PRIS	Power Reactor Information System (IAEA web site)
PUREX	Plutonium Extraction process
PWR	Pressurized Water Reactor
RATA	Radioactive Waste Management Agency (Lithuatia)
RBMK	Light Water Graphite Reactor
RepU	Reprocessed Uranium
RWMC	Radioactive Waste Management Funding and Research Center (Japan)
S3F	Solid Storage Surveillance Facility (India)
SCK-CEN	Belgian Nuclear Research Centre
SKB	Swedish Nuclear Fuel and Waste Management Company
SMP	Sellafield MOX plant (UK)
SNF	spent nuclear fuel
SNL	Sandia National Laboratory
SFR	Final Underground Repository (Sweden)
SKB	Swedish Nuclear Fuel and Waste Management Company
SSE ChNNP	State Specialized Enterprise “Chernobyl NPP” (Ukraine)
SSM	Radiation Safety Authority (Sweden)
STUK	Radiation and Nuclear Safety Authority (Finland)
SWU	Separative Work Unit (of enrichment)
THORPE	Thermal Oxide Reprocessing Plant (UK)
tU	Tons of uranium
UKAEA	United Kingdom Atomic Energy Authority
UFDC	Used Fuel Disposition Campaign
URL	Underground research laboratory
VVER	A PWR design originally developed by the Soviet Union
WAK	Wiederaufarbeirungsanlage Karlsruhe Betriebsgesellschaft (pilot reprocessing plant in Germany)
WANO	World Association of Nuclear Operators
WIP	Waste Immobilization Plant (India)
WIPP	Waste Isolation Pilot Plant (United States)
WNA	World Nuclear Association

LLNL Level 4 Milestone # M41UF032802

1. Introduction

The Used Fuel Disposition Campaign (UFDC) within the Department of Energy's Office of Nuclear Energy (DOE-NE) Fuel Cycle Technology (FCT) program has been tasked with investigating the disposal of the nation's spent nuclear fuel (SNF) and high-level nuclear waste (HLW) for a range of potential waste forms and geologic environments.

This Lessons Learned task is part of a multi-laboratory effort, with this LLNL report providing input to a Level 3 SNL milestone (System-Wide Integration and Site Selection Concepts for Future Disposition Options for HLW). The work package number is: FTLL11UF0328; the work package title is: Technical Bases / Lessons Learned; the milestone number is: M41UF032802; and the milestone title is: "LLNL Input to SNL L3 MS: System-Wide Integration and Site Selection Concepts for Future Disposition Options for HLW".

The system-wide integration effort will integrate all aspects of waste management and disposal, integrating the waste generators, interim storage, transportation, and ultimate disposal at a repository site. The review of international experience in these areas is required to support future studies that address all of these components in an integrated manner.

Note that this report is a snapshot of nuclear power infrastructure and international waste management programs that is current as of August 2011, with one notable exception. No attempt has been made to discuss the currently evolving world-wide response to the tragic consequences of the earthquake and tsunami that devastated Japan on March 11, 2011, leaving more than 15,000 people dead and more than 8,000 people missing, and severely damaging the Fukushima Daiichi nuclear power complex.

Continuing efforts in FY 2012 will update the data, and summarize it in an Excel spreadsheet for easy comparison and assist in the knowledge management of the study cases.

2. Approach

A large number of references were reviewed, but several key sources provided much of the information summarized in this report. Two general review papers provided the basic input to a summary spreadsheet that was prepared.

- The Nuclear Waste Technical Review Board (NWTRB 2011) *Experience Gained From Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries*, and
- The Electric Power Research Institute (EPRI 2010) *EPRI Review of Geologic Disposal for Used Fuel and High Level Radioactive Waste, Volume III—Review of National Repository Programs, Final Report, December 2010*

These two reports concentrated on the most active international nuclear programs, and *Table **1*** shows the countries covered in these two references:

Table 1 – Countries addressed in the NWTRB 2011 and EPRI 2010 international waste management program review reports

Country	**NWTRB 2011**	**EPRI 2010**	**Rank by Nuclear GWe***
Belgium	X	X	13
Canada	X	X	7
China	X	X	9
Finland	X	X	17
France	X	X	2
Germany	X	X	6
Japan		X	3
South Korea	X		5
Spain	X	X	11
Sweden	X	X	10
Switzerland	X	X	15
Taiwan		X	14
United Kingdom	X	X	12
United States	X		1

*See ranking by GWe power generation in 2008 in *Table **2***.

Two other published sources summarizing a large amount of detailed data on existing international nuclear power and high level radioactive waste sources were utilized:

- *World List of Nuclear Power Plants* - Nuclear News March 2011, 13th Annual Reference Issue
- *World Nuclear Industry Handbook* - Nuclear Engineering International Magazine, 2003 (this is an annual publication – later versions available)

These references provided specific information on the names, types, production capacity, commercial operation start dates, operational / construction / and planned status, and specific maps of site locations. This data provides a source for estimating transportation needs and predictions of the potential waste volumes in the international arena.

Several other key sources were web based – the general technical data search engine Wolfram Alpha (http://www.wolframalpha.com), and other web sites providing a large amount of technical papers and data summaries on the international nuclear community for public dissemination and education:

- World Nuclear Association (WNA) (http://world-nuclear.org). The WNA public information web site maintains a suite or around 200 frequently updated and maintained information papers. According to their web site "*The WNA offers this service with the intent that it be a comprehensive and reliably accurate source of information available to the nuclear industry and also to educators, analysts, policymakers, journalists, and citizens around the world.*"

- International Atomic Energy Agency (IAEA)

    - Net-Enabled Radioactive Waste Management Database (NEWMDB). (http://newmdb.iaea.org), which was one of the key resources for the EPRI 2010 report. The NEWMDB contains information on the member nations of the IAEA, and for information on other countries IAEA refers to the WNA web site.

    - IAEA Power Reactor Information System (PRIS). (http://www.iaea.org/programmes/a2/).

    - IAEA country specific profiles of nuclear power and waste management facilities, and waste storage and disposal statistical data (http://newmdb.iaea.org/profiles.aspx)

- US Nuclear Regulatory Commission (NRC)

    - Fact Sheet on Decommissioning Nuclear Power Plants, with table of shut down nuclear power plants and ISFIS status information current as of April 2011. (http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html

- Map showing current ISFSI locations and licensing status in the US (as of March 2011) (http://www.nrc.gov/waste/spent-fuel-storage/locations.html).

IAEA member nations include 55 countries: Argentina, Armenia, Australia, Austria, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, Costa Rica, Croatia, Cuba, Czech Republic, Ecuador, Estonia, Finland, France, Germany, Ghana, Greece, Hungary, India, Indonesia, Islamic Republic of Iran, Ireland, Israel, Italy, Japan, Republic of Korea, Kuwait, Lithuania, Madagascar, Malaysia, Mauritius, Mexico, Netherlands, Norway, Peru, Philippines, Poland, Romania, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, Thailand, Tunisia, Turkey, Ukraine, United Kingdom, and the United States.

*Table **2*** was assembled using the Wolfram Alpha search twice, first to identify countries with measureable nuclear electric power generation (sorted by largest to smallest amounts of generated power – the search results were based on data from 2008), and then to identify the population and area of each country. This table was also used to roughly estimate the MTU of spent nuclear fuel generated, based on an assumption of 26 MTU being produced per GWe-yr of power production (from a fuel cycle diagram in Peterson 2003). The conversion factor of 26 MTU of used fuel produced per GWe-yr is a 'working average' that is representative for many typical power reactors, and can vary significantly (+/- up to a factor of 3) by specific reactor, fuel, burnup and energy conversion.

In addition to spent fuel storage at the operating reactor sites in the United States, there are licensed Independent Spent Fuel Storage Installations (ISFSI), using either wet (pool) storage or dry (cask) storage.

Figure 1 is a map published by the US Nuclear Regulatory Commission on their web page (http://www.nrc.gov/waste/spent-fuel-storage/locations.html) showing current ISFSI locations and licensing status in the US (as of March 2011). A "general" license is issued when an ISFSI is co-located and operated within the site boundaries of an existing operational nuclear power plant. A "site-specific" license requires separate evaluations and documentation that are not required under a general license.

As of August 2011, the IAEA NEWMDB lists 440 nuclear power plants, 419 storage facilities, and 170 waste disposal facilities. *Table **3*** provides a summary of waste storage, processing, and disposal facilities, and lists the total volume of processed and unprocessed waste was either stored or disposed (in cubic meters) for the countries listed in *Table **2***. *Table **3*** was derived from the IAEA member country profile web pages from the facilities summary as well as the waste storage and disposal data sections.

IAEA NEWMDB also provides a detailed breakdown of the waste types that were disposed of or stored. *Table 5* presents a 2008 summary (the most current year with a complete data set) of total values for all IAEA member countries.

Each member country in IAEA may have variations in the way they define and classify their wastes. As a result, IAEA requires its member nations to submit a matrix that maps their wastes and waste definitions to the standard IAEA waste types and definitions. The IAEA uses three general classes of waste:

- LILW_SL – Low and intermediate level short-lived waste
- LILW_LL – Low and intermediate level long-lived waste
- HLW – High level waste

Example matrices for the U.S. DOE and for the U.S. NRC waste classes are presented in *Table 4*.

Section 3 was derived from the World Nuclear Association (WNA) public information web site in August 2011, and it is a current snapshot in 2011 of nuclear power development and status of each of the countries listed in *Table **2***. The countries are listed in alphabetical order in Subsections 3.1 to 3.32. Section 3 does not provide complete coverage for all of the countries with nuclear power plants and waste management programs. It only addresses those countries listed in *Table **2*** (32 out of 208 countries) that had measurable nuclear electric generation in 2008. The data on other countries is can be found on either the WNA Public Information web page (http://world-nuclear.org/infomap.aspx?=atg), or the IAEA NEWMDB member country profiles web pages (http://newmdb.iaea.org/profiles.aspx).

With more or less consistency, the web pages for each country on the WNA public information pages include a discussion of:

- Nuclear industry development
- Uranium resources
- Fuel cycle
- Radioactive waste management
- Regulation and safety
- Non proliferation
- Notes
- References
- General sources

Section 3 only addresses fuel cycle and radioactive waste management related topics, including information on decommissioning and reprocessing in some cases.

*Table **7***, which was also derived from the WNA public information web pages, contains a data table listing all of the world's nuclear power plants including the reactor types, generation capacity, start of commercial operation, and current status. This list is comparable to the ones published by Nuclear News and Nuclear Engineering International.

Section 4 is derived from three of the WNA public information documents, and covers the topic of international radioactive waste transportation.

Table 2 - Countries with Nuclear-Electric Power Generation in 2008
(Sorted in Decreasing Order by Power Generation)[1]

	From Wolfram Alpha web site (2008 data)[1]			GWe-yr *(26 MTU/ GWe-yr)	Data from Nuclear News 13th Annual Reference Issue, March 2011				From Wolfram Alpha web site (2008 data)		From ***Table 1***	
Country	**Rank by Power Production**	**Billion kW-hr generated in 2008**	**Nuclear Electric Generation (GWe-yr)**	**Annual Waste Produced[4] (MTU)**	**No. of Sites**	**Reactors in Operation**	**Reactors Under Construction**	**Reactors Planned**	**Area (Square miles)**	**Population in Millions**	**NWTRB**	**EPRI**
United States[5]	1	806.20	91.97	2,391	65	104	1	8	3.72E+06	309.0	X	
France	2	417.50	47.63	1,238	19	58	1	0	2.11E+05	64.8	X	X
Japan	3	243.60	27.79	723	19	55	2	0	1.46E+05	127.0		X
Russia	4	152.10	17.35	451	12	32	10	2	6.59E+06	140.0		
South Korea	5	143.40	16.36	425	7	20	6	2	3.80E+04	48.5	X	
Germany	6	141.10	16.10	419	12	17	0	0	1.38E+05	82.1	X	X
Canada	7	89.23	10.18	265	5	22	0	0	3.86E+06	33.9	X	X
Ukraine	8	84.30	9.62	250	4	15	2	1	2.33E+05	45.4		
China	9	65.33	7.45	194	19	13	26	17	3.71E+06	1,300.0	X	X
Sweden	10	60.63	6.92	180	3	10	0	0	1.74E+05	9.3	X	X
Spain	11	55.82	6.37	166	6	8	0	0	1.95E+05	45.3	X	X
United Kingdom	12	49.86	5.69	148	9	19	0	0	9.41E+04	61.9	X	X
Belgium[2]	13	43.40	4.95	129	2	7	0	0	1.18E+04	10.7	X	X
Taiwan[2]	14	40.80	4.65	121	4	6	2	0	1.39E+04	23.0		X
Switzerland	15	26.32	3.00	78	4	5	0	0	1.59E+04	7.6	X	X
Czech Republic	16	25.22	2.88	75	2	6	0	0	3.05E+04	10.4		
Finland	17	21.79	2.49	65	2	4	1	0	1.31E+05	5.4	X	X
Slovakia	18	15.87	1.81	47	2	4	2	0	1.89E+04	5.4		
Bulgaria	19	14.74	1.68	44	2	2	0	2	4.28E+04	7.5		
Hungary	20	14.08	1.61	42	1	4	0	0	3.59E+04	10.0		

Table 2 (cont'd)	From Wolfram Alpha web site (2008 data)[1]			GWe-yr *(26 MTU/ GWe-yr)	Data from Nuclear News 13th Annual Reference Issue, March 2011				From Wolfram Alpha web site (2008 data)		From ***Table 1***	
Country	**Rank by Power Production**	**Billion kW-hr generated in 2008**	**Nuclear Electric Generation (GWe-yr)**	**Annual Waste Produced[4] (MTU)**	**No. of Sites**	**Reactors in Operation**	**Reactors Under Construction**	**Reactors Planned**	**Area (Square miles)**	**Population in Millions**	**NWTRB**	**EPRI**
Brazil	21	13.97	1.59	41	1	2	1	0	3.29E+06	195.0		
India	22	13.17	1.50	39	8	20	4	3	1.27E+06	1,210.0		
South Africa	23	11.32	1.29	34	1	2	0	0	4.71E+05	50.5		
Romania	24	10.33	1.18	31	1	2	3	0	9.20E+04	21.2		
Mexico	25	9.31	1.06	28	1	2	0	0	7.58E+05	111.0		
Lithuania[3]	26	9.14	1.04	27	1	0	0	0	2.52E+04	3.3		
Argentina	27	6.84	0.78	20	2	2	1	0	1.07E+06	40.7		
Slovenia	28	5.97	0.68	18	1	1	0	0	7.83E+03	2.0		
Netherlands	29	3.96	0.45	12	1	1	0	0	1.60E+04	16.7		
Armenia	30	2.27	0.26	7	1	1	0	0	1.15E+04	3.1		
Pakistan	31	1.74	0.20	5	2	2	1	0	3.07E+05	185.0		
Iran	32	0.00	0.00	0	1	1	0	0	6.36E+05	75.1		
Totals		**2,599**	**297**	**7,710**	**220**	**447**	**63**	**35**	**27,351,515**	**4,260.7**	**12**	**12**

Notes:

1. The list of all reactors with some amount of power production in 2008 from the Wolfram Alpha search includes a total of 208 countries.
2. Data for Belgium and Taiwan electric production in 2008 is from the World Nuclear Association database
3. Lithuania closed its last operating nuclear reactor in 2009.
4. The conversion factor of 26 MTU of used fuel produced per GWe-yr (Peterson 2003) is a 'working average' that is representative for many ty reactors, and can vary significantly (+/- up to a factor of 3) by specific reactor, fuel, burnup and energy conversion.
5. This table shows the 104 operating reactors in the United States. There are also 14 shut down reactor sites with Independent Spent Fuel Storage Facilities (ISFSI) and fuel still on site (NRC Fact Sheet 2011). Four (4) of the 14 shut down sites with ISFSIs are at sites with other ope Leaving 10 "stranded" sites (Kadak and Yost 2010).

Table 3 - Waste Management Facilities, Waste Storage, and Disposal Data

	Waste Management Facilities				Waste in Storage All Classes (m^3)		Waste Disposal All Classes (m^3)		
Country	**Disposal Facilities**	**Storage Facilities**	**Processing Facilities**	**Year of First Disposal**	**Not Processed**	**Processed**	**Not Processed**	**Processed**	**Year of Data Summary**
Argentina	3	11	6	1969	651	1,033	0	2,924	2008
Armenia	No Report	No Report	No Report	No Report	No Report	No Report	No Report	No Report	No Report
Belgium	1	13	10	1960	46,601	18,638	0	15,765	2007
Brazil	3	5	5	1995	485	2,679	0	3,500	2008
Bulgaria	4	9	5	1964	11,188	5,534	220	25	2008
Canada	0	22	4	NA	2,893,710	0	NA	NA	2006
China	0	8	10	NA	No Report	No Report	No Report	No Report	No Report
Czech Republic	4	10	11	1959	987	1,992	554	6,693	2008
Finland	4	10	5	1992	2,564	286	0	6,516	2008
France	3	8	6	1969	0	321,024	0	711,692	2006
Germany	3	18	4	1971	29,689	89,546	0	36,753	2007
Hungary	3	2	4	1977	2,217	6,825	3,326	1,714	2008
India	No Report	No Report	No Report	No Report	No Report	No Report	No Report	No Report	No Report
Iran	1	2	1	1976	1	27	5,990	0	2008
Japan	4	38	13	1992	218,765	11,222	0	41,794	2007
Lithuania	0	4	3	NA	24,144	15,142	NA	NA	2008
Mexico	2	6	2	1985	124	3,452	38	20,858	2008
Netherlands	0	1	3	NA	6,449	9,374	NA	NA	2008
Pakistan	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA
Romania	1	3	2	1985	427	2	0	1,868	2008
Russia	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA
Slovakia	3	5	6	2001	14,064	1,176	0	5,558	2008

Table 3 (cont'd)

	Waste Management Facilities				Waste in Storage All Classes (m^3)		Waste Disposal All Classes (m^3)		
Country	**Disposal Facilities**	**Storage Facilities**	**Processing Facilities**	**Year of First Disposal**	**Not Processed**	**Processed**	**Not Processed**	**Processed**	**Year of Data Summary**
Slovenia	1	3	1	2011	1,044	2,265	NA	NA	2008
South Africa	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA
South Korea	0	9	7	NA	0	21,343	NA	NA	2008
Spain	2	15	13	1993	2,157	11,760	0	55,988	2007
Sweden	7	3	19	1987	634	2,913	0	47,567	2008
Switzerland	5	8	10	1969	1,047	5,931	0	2,308	2008
Taiwan	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA	Not in IAEA
Ukraine	27	20	6	1961	1,365,953	8,738	626,908	860	2008
United Kingdom	2	49	51	1969	186,885	156,358	800,000	34,000	2008
United States	34	24	21	1945	454,582	77,242	18,752,470	3,980,270	2008
Totals	**117**	**306**	**228**		**5,264,368**	**774,502**	**20,189,506**	**4,976,653**	

Notes:
1. IAEA provides additional breakdown of waste sources by RO (Reactor Operations), FFE (Fuel Fabrication / Enrichment), RP (Reprocessing), NA (Nuclear Applications), DF (Defense), DC/RE (Decommissioning / Remediation), and ND (Not Determined).

Table 4 - U.S. DOE and NRC IAEA Waste Class Matrix Examples

International Atomic Energy Agency | Page 1 of 2 | NEWMDB Report

Waste Class Matrix(ces) Used/Defined

Country: United States of America | Reporting Year: 2008

Waste Class Matrix: IAEA Def. , Not Used

Description: The Agency's standard matrix

Waste Class Matrix: USDOE

Waste Class Name	LILW_SL%	LILW_LL%	HLW%
HLW	0	0	100
TRU	0	100	0
LLW	99.5	0.5	0
11e2 Byproduct Material	100	0	0

Description: Reference for USDOE classes: Radioactive Waste Management Manual, DOE M 435.1, 7/9/1999

Comment #85: Waste Class Comment

The US DOE has a waste class called "11e2" which is essentially by-product material. Keeping with NEWMDB guidance, this year "exsitu" remediation waste, e.g., moved to a disposal cell, will be reported. UMMT disposal cells will not be reported.

Attachment #1622: White paper with DOE waste classfication information and crosswalk to IAEA

File name: DOEwastematrix.wpd

File type: WordPerfect Document

Member State's Reference # 1

Waste Class Matrix: USNRC

Waste Class Name	LILW_SL%	LILW_LL%	HLW%
Class A LLW	100	0	0
Class B LLW	100	0	0
Class C LLW	75	25	0
Greater than Class C LLW	0	100	0
HLW	0	0	100
11e2 Byproduct Material	100	0	0

Description: NRC waste classes defined in Title 10, Code of Federal Regulations, Part 61, Subpart 55. 11e2 byproduct materials are not waste under Part 61 regulations. See separate comment on this NEWMDB reporting class.
Class C split based on analysis of actual data

Comment #7234: USNRC - 11e2

11e2 materials by definition are byproduct materials under regulations. These materials are composed of UMMT or equivalent. However, because the NEWMDB reporting requirements address UMMT materials that are moved, there is a need to have this shown as a waste class. The waste class does not fit the IAEA categories, but since surface disposed, for NEMWDB reporting is shown as 100% LILW-SL.

Attachment #1621: White paper on USNRC waste classification crosswalk to IAEA classes

File name: NRCwastematrix.wpd

File type: WordPerfect Document

Member State's Reference # 2

Table 4 - U.S. DOE and NRC IAEA Waste Class Matrix Examples (cont'd)

International Atomic Energy Agency | Page 2 of 2 | NEWMDB Report

Waste Class Matrix(ces) Used/Defined

Country: United States of America | Reporting Year: 2008

Waste Class Matrix: Past

Waste Class Name	LILW_SL%	LILW_LL%	HLW%
Ocean-disposed	99	1	0

Description: Between 1946 and 1970 the United States disposed of waste at several locations in the Atlantic Ocean and Pacific Ocean before such practices were discontinued under the London Convention. The % split between the LILW-SL and LILW-LL is an approximation.

Definition of «unprocessed waste» and «processed waste»:

This country uses the following definitions:

	as-generated waste	processed for handling	processed for storage	processed for disposal
unprocessed	X	X	X	
processed				X

Comment #14543: Definitions for Unprocessed Waste and Processed W

The definition used by the USA generally means that waste packaged for (long-term) storage or disposal is reported as processed. Remedial action waste, e.g., debris and soils, are generally disposed of as unprocessed waste because they are shipped and disposed in bulk form. In the case of mixed radioactive and hazardous waste, the waste has been treated in accordance with hazardous waste regulations.

Table 5 - World Summary of Radioactive Waste Origin and Volumes

All Countries 2008 (from IAEA NEWMDB)

Waste Class/Origin	Unprocessed Storage (m^3)	Processed Storage (m^3)	Unprocessed Disposal (m^3)	Processed Disposal (m^3)
LILW_SL	**1,802,488.6**	**513,973.1**	**19,485,691.7**	**4,863,066.7**
Decommissioning/Remediation	1,325,703.1	38,200.7	17,213,471.7	614,232.7
Defense	5,845.7	68,955.8	1,248,536.6	1,801,679.6
Fuel Fabrication/Enrichment	27,954.9	36,359.2	0.0	306,674.2
Not Determined/Unknown	4,260.3	7,127.0	1,068.0	558,914.4
Nuclear Applications	119,662.2	107,034.4	588,434.6	422,826.3
Reactor Operation	252,655.6	141,943.9	434,180.8	1,061,396.1
Reprocessing	66,406.7	114,352.3	0.0	97,343.3
LILW_LL	**3,104,530.8**	**117,071.3**	**125,501.5**	**82,317.0**
Decommissioning/Remediation	2,380,319.5	3,283.0	116,920.9	947.2
Defense	81,599.8	853.2	6,515.0	66,917.5
Fuel Fabrication/Enrichment	3,784.4	19,006.2	0.0	93.8
Not Determined/Unknown	325.4	661.1	998.0	431.8
Nuclear Applications	50,707.9	34,383.8	489.5	2,522.8
Reactor Operation	556,433.3	13,409.4	578.2	11,285.5
Reprocessing	31,360.3	45,474.6	0.0	118.3
HLW	**358,497.7**	**5,081.2**	**3,960.0**	**10.0**
Decommissioning/Remediation	10.2	2.7	3,960.0	0.0
Defense	354,998.0	2,000.0	0.0	0.0
Fuel Fabrication/Enrichment	16.7	55.5	0.0	0.0
Nuclear Applications	248.2	147.5	0.0	0.0
Reactor Operation	794.4	29.0	0.0	10.0
Reprocessing	2,430.2	2,846.4	0.0	0.0

Note: As defined by IAEA, LILW_SL are short-lived low- and intermediate-level wastes, and LILW_LL are long-lived low- and intermediate-level wastes.

Figure 1 - U.S. Independent Spent Fuel Storage Installations

3. Current International Nuclear Waste Management Status summary

*Table **6*** lists the types of nuclear reactors in commercial operation by country. *Table 8* provides an overview of the fuel cycles, waste management host environments, and research sites covered in EPRI 2010 for those countries listed under EPRI in *Table **1***.

The following summary of international radioactive waste management programs covers the 32 countries listed in *Table **2***.

The information on the back-end of the fuel cycles, waste management programs, and in some cases including decommissioning information for each country has been extracted from both IAEA and WNA web sites current as of 2011. The sections are presented by country in alphabetical order.

Table 6 - Types of Nuclear Power Plants in Commercial Operation

Reactor type	Main Countries	Number	GWe	Fuel	Coolant	Moderator
Pressurized Water Reactor (PWR)	US, France, Japan, Russia, China	265	251.6	enriched UO_2	water	water
Boiling Water Reactor (BWR)	US, Japan, Sweden	94	86.4	enriched UO_2	water	water
Pressurized Heavy Water Reactor 'CANDU' (PHWR)	Canada[1]	44	24.3	natural UO_2	heavy water	heavy water
Gas-cooled Reactor (AGR & Magnox)	UK	18	10.8	natural U (metal), enriched UO_2	CO_2	graphite
Light Water Graphite Reactor (RBMK)	Russia	12	12.3	enriched UO_2	water	graphite
Fast Neutron Reactor (FBR)	Japan, Russia[2]	2	1	PuO_2 and UO_2	liquid sodium	none
Other[3]	Russia	4	0.05	enriched UO_2	water	graphite
	Totals	439	386.5			

Source: Nuclear Engineering International Handbook 2010, as cited on the WNA Public Information web page

Notes:
1. CANDU reactors are also used by Argentina, China, India, Romania, and South Korea (WNA Public Information pages)
2. France had two fast breeder reactors which have been shut down (WNA Public Information pages for France)
3. Other = LWGR/EGP graphite moderated boiling water reactors (from *Table 7*)

Table 7 - World List of Nuclear Reactors

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Argentina	Atucha-1	PHWR	335	Operating	1974	Nucleoelectrica Argentina SA
Argentina	Atucha-2	PHWR	692	Under construction		Nucleoelectrica Argentina SA
Argentina	Embalse	PHWR	600	Operating	1984	Nucleoelectrica Argentina SA
Armenia	Armenia-1 (Metsamor)	PWR	376	Shut down	1979	JSC Armenia NPP
Armenia	Armenia-2 (Metsamor)	PWR/VVER	376	Operating	1980	JSC Armenia NPP
Austria	Tullnerfeld	BWR	692	Suspended indefinitely/Cancelled		Gemeinschaftskernkraft werk Tullnerfeld (GKT)
Belarus	Minsk-1	PWR/VVER	900	Suspended indefinitely/Cancelled		Ministry of Atomic Energy and Industry (MAEI)
Belgium	BR-3 PWR (test)	PWR	11	Shut down	1962	SCK.CEN
Belgium	Doel-1	PWR	433	Operating	1975	Indivision Doel (EBES, INTERCOM, UNERG)
Belgium	Doel-2	PWR	392	Operating	1975	Indivision Doel (EBES, INTERCOM, UNERG)
Belgium	Doel-3	PWR	985	Operating	1982	Indivision Doel (EBES, INTERCOM, UNERG)
Belgium	Doel-4	PWR	1039	Operating	1985	Indivision Doel (EBES, INTERCOM, UNERG)
Belgium	Tihange-1	PWR	962	Operating	1975	Electrabel
Belgium	Tihange-2	PWR	1008	Operating	1983	Electrabel
Belgium	Tihange-3	PWR	1015	Operating	1985	Electrabel
Brazil	Angra-1	PWR	626	Operating	1985	Eletronuclear
Brazil	Angra-2	PWR	1270	Operating	2001	Eletronuclear
Brazil	Angra-3	PWR	1270	Under construction		Eletronuclear
Bulgaria	Belene-1	PWR	1060	Planned		

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Bulgaria	Belene-1 (Past Project)	PWR/VVER	953	Suspended indefinitely/Cancelled		National Electricity Co (NEC)
Bulgaria	Belene-2	PWR	1060	Planned		
Bulgaria	Kozloduy-1	PWR/VVER	408	Shut down	1974	National Electricity Co (NEC)
Bulgaria	Kozloduy-2	PWR/VVER	408	Shut down	1975	National Electricity Co (NEC)
Bulgaria	Kozloduy-3	PWR/VVER	408	Shut down	1981	National Electricity Co (NEC)
Bulgaria	Kozloduy-4	PWR/VVER	408	Shut down	1982	National Electricity Co (NEC)
Bulgaria	Kozloduy-5	PWR/VVER	953	Operating	1988	National Electricity Co (NEC)
Bulgaria	Kozloduy-6	PWR/VVER	953	Operating	1993	National Electricity Co (NEC)
Canada	Bruce-1	PHWR/CANDU	769	Not operating	1977	Ontario Hydro
Canada	Bruce-2	PHWR/CANDU	769	Not operating	1977	Ontario Power Generation (OPG)
Canada	Bruce-3	PHWR/CANDU	769	Operating	1978	Ontario Power Generation (OPG)
Canada	Bruce-4	PHWR/CANDU	769	Operating	1979	Ontario Power Generation (OPG)
Canada	Bruce-5	PHWR/CANDU	785	Operating	1985	Ontario Power Generation (OPG)
Canada	Bruce-6	PHWR/CANDU	785	Operating	1984	Ontario Power Generation (OPG)
Canada	Bruce-7	PHWR/CANDU	785	Operating	1986	Ontario Power Generation (OPG)
Canada	Bruce-8	PHWR/CANDU	785	Operating	1987	Ontario Power Generation (OPG)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Canada	Darlington-1	PHWR/CANDU	881	Operating	1992	Ontario Power Generation (OPG)
Canada	Darlington-2	PHWR/CANDU	881	Operating	1990	Ontario Power Generation (OPG)
Canada	Darlington-3	PHWR/CANDU	881	Operating	1993	Ontario Power Generation (OPG)
Canada	Darlington-4	PHWR/CANDU	881	Operating	1993	Ontario Power Generation (OPG)
Canada	Douglas Point (Prototype)	PHWR/CANDU	206	Shut down	1968	Atomic Energy of Canada Ltd (AECL)
Canada	Gentilly-1 (Demo)	HWLWR/CANDU	250	Shut down	1972	Hydro-Quebec
Canada	Gentilly-2	PHWR/CANDU	638	Operating	1983	Hydro-Quebec
Canada	Pickering-1	PHWR/CANDU	515	Operating	1971	Ontario Hydro
Canada	Pickering-2	PHWR/CANDU	515	Not operating	1971	Ontario Hydro
Canada	Pickering-3	PHWR/CANDU	515	Not operating	1972	Ontario Hydro
Canada	Pickering-4	PHWR/CANDU	515	Operating	1973	Ontario Hydro
Canada	Pickering-5	PHWR/CANDU	516	Operating	1983	Ontario Hydro
Canada	Pickering-6	PHWR/CANDU	516	Operating	1984	Ontario Power Generation (OPG)
Canada	Pickering-7	PHWR/CANDU	516	Operating	1985	Ontario Hydro
Canada	Pickering-8	PHWR/CANDU	516	Operating	1986	Ontario Hydro
Canada	Point Lepreau	PHWR/CANDU	635	Operating	1983	New Brunswick Power
Canada	Rolphton NPD (Demo)	PHWR/CANDU	22	Shut down	1962	Atomic Energy of Canada Ltd (AECL)
China, mainland	Changjiang 1 (Phase I, Unit 1)	PWR	600	Under construction		China National Nuclear Corp (CNNC)
China, mainland	Changjiang 2 (Phase I, Unit 2)	PWR	600	Under construction		China National Nuclear Corp (CNNC)
China, mainland	Chinese Experimental Fast Reactor (CEFR)	FBR	20	Operating		China Institute of Atomic Energy

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
China, mainland	Dafan, Xianning 1	PWR		Planned		
China, mainland	Dafan, Xianning 2	PWR		Planned		
China, mainland	Daya Bay 1 (Guangdong-1)	PWR	944	Operating	1994	Guangdong Nuclear Power JVC (GNP JVC)
China, mainland	Daya Bay 2 (Guangdong-2)	PWR	944	Operating	1994	Guangdong Nuclear Power JVC (GNP JVC)
China, mainland	Fangchenggang 1 (Phase I, Unit 1) (Hongsha 1)	PWR	1000	Under construction		China Guangdong Nuclear Power Co (CGNPC)
China, mainland	Fangchenggang 2 (Phase I, Unit 2) (Hongsha 2)	PWR	1000	Planned		China Guangdong Nuclear Power Co (CGNPC)
China, mainland	Fangjiashan 1 (Phase 1, unit 1)	PWR	1000	Under construction		China National Nuclear Corp (CNNC)
China, mainland	Fangjiashan 2 (Phase 1, unit 2)	PWR	1000	Under construction		China National Nuclear Corp (CNNC)
China, mainland	Fuqing-1 (Phase I, unit 1)	PWR	1000	Under construction		China National Nuclear Corp (CNNC)
China, mainland	Fuqing-2 (Phase I, unit 2)	PWR	1000	Under construction		China National Nuclear Corp (CNNC)
China, mainland	Fuqing-3	PWR	1000	Under Construction		
China, mainland	Fuqing-4	PWR	1000	Planned		
China, mainland	Fuqing-5	PWR	1000	Planned		
China, mainland	Fuqing-6	PWR	1000	Planned		
China, mainland	Haiyang 1	PWR		Under construction		
China, mainland	Haiyang 2	PWR		Planned		
China, mainland	Haiyang 3	PWR		Planned		
China, mainland	Haiyang 4	PWR		Planned		
China, mainland	Hongshiding-1 (Rushan-1)	PWR	1000	Planned		
China, mainland	Hongshiding-2 (Rushan-2)	PWR	1000	Planned		

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
China, mainland	Hongyanhe 1	PWR	1000	Under construction		
China, mainland	Hongyanhe 2	PWR	1000	Under construction		
China, mainland	Hongyanhe 3	PWR	1000	Under construction		
China, mainland	Hongyanhe 4	PWR	1000	Under construction		
China, mainland	Lingao-1	PWR	935	Operating	2002	Lingao Nuclear Power Co
China, mainland	Lingao-2	PWR	935	Operating	2003	Lingao Nuclear Power Co
China, mainland	Lingao-3	PWR	1000	Operating	2010	Guangdong Nuclear Power JVC (GNP JVC)
China, mainland	Lingao-4	PWR	1000	Under construction		Guangdong Nuclear Power JVC (GNP JVC)
China, mainland	Ningde 1	PWR	1000	Under construction		
China, mainland	Ningde 2	PWR	1000	Under construction		
China, mainland	Ningde 3	PWR	1000	Under construction		
China, mainland	Ningde 4	PWR	1000	Under construction		
China, mainland	Ningde 5	PWR	1000	Planned		
China, mainland	Ningde 6	PWR	1000	Planned		
China, mainland	Pengze 1	PWR		Planned		
China, mainland	Pengze 2	PWR		Planned		
China, mainland	Qinshan-1 (Phase I)	PWR	279	Operating	1994	China National Nuclear Corp (CNNC)
China, mainland	Qinshan-2 (Phase II, Unit 1)	PWR	610	Operating	2002	China National Nuclear Corp (CNNC)
China, mainland	Qinshan-3 (Phase II, Unit 2)	PWR	610	Operating	2004	China National Nuclear Corp (CNNC)
China, mainland	Qinshan-4 (Phase III, Unit 1)	PHWR/CANDU	665	Operating	2002	China National Nuclear Corp (CNNC)
China, mainland	Qinshan-5 (Phase III, Unit 2)	PHWR/CANDU	665	Operating	2003	China National Nuclear Corp (CNNC)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
China, mainland	Qinshan-6 (Phase II, Unit 3)	PWR	650	Operating	2010	China National Nuclear Corp (CNNC)
China, mainland	Qinshan-7 (Phase II, Unit 4)	PWR	650	Under construction	2011	China National Nuclear Corp (CNNC)
China, mainland	Sanmen-1	PWR	1117	Under construction		China National Nuclear Corp (CNNC)
China, mainland	Sanmen-2	PWR	1117	Under construction		China National Nuclear Corp (CNNC)
China, mainland	Shandong Shidaowan	HTR-PM		Planned		
China, mainland	Taishan 1	PWR	1650	Under construction		Guangdong Taishan Nuclear Power Joint Venture Co Ltd (TNPC) (CGNPC 70% + EdF 30%)
China, mainland	Taishan 2	PWR	1650	Under construction		Guangdong Taishan Nuclear Power Joint Venture Co Ltd (TNPC)
China, mainland	Taohuajiang 1	PWR		Planned		
China, mainland	Taohuajiang 2	PWR		Planned		
China, mainland	Taohuajiang 3	PWR		Planned		
China, mainland	Taohuajiang 4	PWR		Planned		
China, mainland	Tianwan-1	PWR	950	Operating	2006	Jiangsu Nuclear Power Corp (CNNC)
China, mainland	Tianwan-2	PWR	950	Operating	2007	Jiangsu Nuclear Power Corp (CNNC)
China, mainland	Tianwan-3	PWR	1000	Planned		
China, mainland	Tianwan-4	PWR	1000	Planned		
China, mainland	Tianwan-5	PWR	1200	Planned		
China, mainland	Tianwan-6	PWR	1200	Planned		
China, mainland	Wuhu 1	PWR	1117	Planned		
China, mainland	Xiaomoshan (Jiulongshan) 1	PWR		Planned		

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
China, mainland	Xiaomoshan (Jiulongshan) 2	PWR		Planned		
China, mainland	Yangjiang-1	PWR	1000	Under construction		Guangdong Nuclear Power JVC (GNP JVC)
China, mainland	Yangjiang-2	PWR	900	Under construction		Guangdong Nuclear Power JVC (GNP JVC)
China, mainland	Yangjiang-3	PWR	1000	Under construction		CGNPC, CLP
China, mainland	Yangjiang-4	PWR	1000	Planned		
Cuba	Juragua-1	PWR/VVER	408	Construction suspended		
Cuba	Juragua-2	PWR/VVER	408	Construction suspended		
Czech Republic	Dukovany-1	PWR	428	Operating	1985	CEZ
Czech Republic	Dukovany-2	PWR	412	Operating	1986	CEZ
Czech Republic	Dukovany-3	PWR	471	Operating	1986	CEZ
Czech Republic	Dukovany-4	PWR	470	Operating	1986	CEZ
Czech Republic	Temelin-1	PWR	963	Operating	2002	CEZ
Czech Republic	Temelin-2	PWR	963	Operating	2002	CEZ
Czech Republic	Temelin-3	PWR/VVER	600	Suspended indefinitely/Cancelled		CEZ
Czech Republic	Temelin-4	PWR/VVER	600	Suspended indefinitely/Cancelled		CEZ
Egypt	El Dabaa-1		1000	Planned		Egyptian Atomic Energy Authority (AEA)
Finland	Loviisa-1	PWR/VVER	488	Operating	1977	Fortum Power and Heat Oy
Finland	Loviisa-2	PWR/VVER	488	Operating	1981	Fortum Power and Heat Oy
Finland	Olkiluoto-1	BWR	840	Operating	1979	Teollisuuden Voima Oy (TVO)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Finland	Olkiluoto-2	BWR	860	Operating	1982	Teollisuuden Voima Oy (TVO)
Finland	Olkiluoto-3	PWR	1600	Under construction		Teollisuuden Voima Oy (TVO)
France	Belleville-1	PWR	1310	Operating	1988	Electricite de France (EdF)
France	Belleville-2	PWR	1310	Operating	1989	Electricite de France (EdF)
France	Blayais-1	PWR	910	Operating	1981	Electricite de France (EdF)
France	Blayais-2	PWR	910	Operating	1983	Electricite de France (EdF)
France	Blayais-3	PWR	910	Operating	1983	Electricite de France (EdF)
France	Blayais-4	PWR	910	Operating	1983	Electricite de France (EdF)
France	Bugey-1	GCR	540	Shut down	1972	Electricite de France (EdF)
France	Bugey-2	PWR	910	Operating	1979	Electricite de France (EdF)
France	Bugey-3	PWR	910	Operating	1979	Electricite de France (EdF)
France	Bugey-4	PWR	880	Operating	1979	Electricite de France (EdF)
France	Bugey-5	PWR	900	Operating	1980	Electricite de France (EdF)
France	Cattenom-1	PWR	1300	Operating	1987	Electricite de France (EdF)
France	Cattenom-2	PWR	1300	Operating	1988	Electricite de France (EdF)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
France	Cattenom-3	PWR	1300	Operating	1991	Electricite de France (EdF)
France	Cattenom-4	PWR	1300	Operating	1992	Electricite de France (EdF)
France	Chinon-1	GCR	70	Shut down	1964	Electricite de France (EdF)
France	Chinon-2	GCR	210	Shut down	1965	Electricite de France (EdF)
France	Chinon-3	GCR	480	Shut down	1966	Electricite de France (EdF)
France	Chinon-B1	PWR	905	Operating	1984	Electricite de France (EdF)
France	Chinon-B2	PWR	905	Operating	1984	Electricite de France (EdF)
France	Chinon-B3	PWR	905	Operating	1987	Electricite de France (EdF)
France	Chinon-B4	PWR	905	Operating	1988	Electricite de France (EdF)
France	Chooz-A (Prototype)	PWR	310	Shut down	1967	Electricite de France (EdF)
France	Chooz-B1	PWR	1500	Operating	2000	Electricite de France (EdF)
France	Chooz-B2	PWR	1500	Operating	2000	Electricite de France (EdF)
France	Civaux-1	PWR	1495	Operating	2002	Electricite de France (EdF)
France	Civaux-2	PWR	1495	Operating	2002	Electricite de France (EdF)
France	Cruas-1	PWR	915	Operating	1984	Electricite de France (EdF)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
France	Cruas-2	PWR	915	Operating	1985	Electricite de France (EdF)
France	Cruas-3	PWR	915	Operating	1984	Electricite de France (EdF)
France	Cruas-4	PWR	915	Operating	1985	Electricite de France (EdF)
France	Dampierre-1	PWR	890	Operating	1980	Electricite de France (EdF)
France	Dampierre-2	PWR	890	Operating	1981	Electricite de France (EdF)
France	Dampierre-3	PWR	890	Operating	1981	Electricite de France (EdF)
France	Dampierre-4	PWR	890	Operating	1981	Electricite de France (EdF)
France	Fessenheim-1	PWR	880	Operating	1977	Electricite de France (EdF)
France	Fessenheim-2	PWR	880	Operating	1978	Electricite de France (EdF)
France	Flamanville-1	PWR	1330	Operating	1986	Electricite de France (EdF)
France	Flamanville-2	PWR	1330	Operating	1987	Electricite de France (EdF)
France	Flamanville-3	PWR	1650	Under construction		Electricite de France (EdF)
France	G-2 (Marcoule)	GCR	38	Shut down	1959	CEA/EDF
France	G-3 (Marcoule)	GCR	38	Shut down	1960	CEA/EDF
France	Golfech-1	PWR	1310	Operating	1991	Electricite de France (EdF)
France	Golfech-2	PWR	1310	Operating	1994	Electricite de France (EdF)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
France	Gravelines-1	PWR	915	Operating	1980	Electricite de France (EdF)
France	Gravelines-2	PWR	915	Operating	1980	Electricite de France (EdF)
France	Gravelines-3	PWR	915	Operating	1981	Electricite de France (EdF)
France	Gravelines-4	PWR	915	Operating	1981	Electricite de France (EdF)
France	Gravelines-5	PWR	915	Operating	1985	Electricite de France (EdF)
France	Gravelines-6	PWR	915	Operating	1985	Electricite de France (EdF)
France	Nogent-1	PWR	1310	Operating	1988	Electricite de France (EdF)
France	Nogent-2	PWR	1310	Operating	1989	Electricite de France (EdF)
France	Paluel-1	PWR	1330	Operating	1985	Electricite de France (EdF)
France	Paluel-2	PWR	1330	Operating	1985	Electricite de France (EdF)
France	Paluel-3	PWR	1330	Operating	1986	Electricite de France (EdF)
France	Paluel-4	PWR	1330	Operating	1986	Electricite de France (EdF)
France	Penly-1	PWR	1330	Operating	1990	Electricite de France (EdF)
France	Penly-2	PWR	1330	Operating	1992	Electricite de France (EdF)
France	Penly-3	PWR	1620	Planned		

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
France	Phenix	FBR	233	Shut down	1974	Commissariat a l"Energie Atomique (CEA)
France	St. Alban-1	PWR	1335	Operating	1986	Electricite de France (EdF)
France	St. Alban-2	PWR	1335	Operating	1987	Electricite de France (EdF)
France	St. Laurent-A1	GCR	480	Shut down	1969	Electricite de France (EdF)
France	St. Laurent-A2	GCR	515	Shut down	1971	Electricite de France (EdF)
France	St. Laurent-B1	PWR	915	Operating	1983	Electricite de France (EdF)
France	St. Laurent-B2	PWR	915	Operating	1983	Electricite de France (EdF)
France	Super-Phenix	FBR	1200	Shut down		NERSA
France	Tricastin-1	PWR	915	Operating	1980	Electricite de France (EdF)
France	Tricastin-2	PWR	915	Operating	1980	Electricite de France (EdF)
France	Tricastin-3	PWR	880	Operating	1981	Electricite de France (EdF)
France	Tricastin-4	PWR	880	Operating	1981	Electricite de France (EdF)
Germany	Biblis-A	PWR	1167	Operating	1975	RWE Power AG
Germany	Biblis-B	PWR	1240	Operating	1977	RWE Power AG
Germany	Brokdorf	PWR	1370	Operating	1986	EON Kernkraft GmbH
Germany	Brunsbuttel	BWR	771	Operating	1977	Hamburgische Electricitaetswerke AG (HEW)
Germany	Emsland	PWR	1329	Operating	1988	RWE Power AG

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Germany	Grafenrheinfeld	PWR	1275	Operating	1982	EON Kernkraft GmbH
Germany	Greifswald-1	PWR/VVER	408	Shut down	1974	EWN
Germany	Greifswald-2	PWR/VVER	408	Shut down	1975	EWN
Germany	Greifswald-3	PWR/VVER	408	Shut down	1978	EWN
Germany	Greifswald-4	PWR/VVER	408	Shut down	1979	EWN
Germany	Greifswald-5	PWR/VVER	408	Shut down	1989	EWN
Germany	Greifswald-6	PWR/VVER	408	Suspended indefinitely/Cancelled		Treuhand
Germany	Grohnde	PWR	1360	Operating	1985	EON Kernkraft GmbH
Germany	Grosswelzheim	BWR	23	Shut down	1970	KfK
Germany	Gundremmingen KRB-A	BWR	237	Shut down	1967	RWE Energie AG
Germany	Gundremmingen-B	BWR	1284	Operating	1984	RWE Power AG
Germany	Gundremmingen-C	BWR	1288	Operating	1985	RWE Power AG
Germany	Isar-1	BWR	878	Operating	1979	EON Kernkraft GmbH
Germany	Isar-2	PWR	1400	Operating	1988	EON Kernkraft GmbH
Germany	Juelich AVR	HTGR	13	Shut down	1969	Arbeitsgemeinschaft Versuchsreaktor GmbH (AVR)
Germany	Kahl VAK	BWR	15	Shut down	1962	VAK
Germany	Kalkar (SN300)	FBR	295	Suspended indefinitely/Cancelled		Schnell-Brueter-Kernkraftwerks-Gesellschaft (SBK)
Germany	Karlsruhe MZFR	PHWR	52	Shut down	1966	KBG
Germany	KNK-II	FBR	17	Shut down	1977	Kernkraftwerk
Germany	Krummel	BWR	1260	Operating	1984	EON Kernkraft / Hamburgische Electricitaetswerke AG (HEW)
Germany	Lingen KWL	BWR	240	Shut down	1968	KWL

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Germany	Muelheim-Karlich	PWR	1219	Shut down	1987	RWE Energie AG
Germany	Neckarwestheim-1	PWR	785	Operating	1976	EnBW Kraftwerk AG
Germany	Neckarwestheim-2	PWR	1310	Operating	1989	EnBW Kraftwerk AG
Germany	Niederaichbach (KKN)	HWGCR	100	Shut down	1973	Bayernwerk Kernernergie GmbH
Germany	Obrigheim	PWR	340	Shut down	1969	EnBW Kraftwerk AG
Germany	Philippsburg-1	BWR	890	Operating	1980	EnBW Kraftwerk AG
Germany	Philippsburg-2	PWR	1392	Operating	1985	EnBW Kraftwerk AG
Germany	Rheinsberg KKR	PWR/VVER	62	Shut down	1966	EWN
Germany	Stade	PWR	640	Shut down	1972	EON Kernkraft GmbH
Germany	Stendal-1	PWR/VVER	950	Suspended indefinitely/Cancelled		VEB
Germany	Stendal-2	PWR/VVER	950	Suspended indefinitely/Cancelled		VEB
Germany	THTR-300	HTGR	296	Shut down	1987	HKG
Germany	Unterweser	PWR	1345	Operating	1979	EON Kernkraft GmbH
Germany	Wurgassen	BWR	640	Shut down	1975	EON Kernkraft GmbH
Hungary	Paks-1	PWR	470	Operating	1983	MVM
Hungary	Paks-2	PWR	473	Operating	1984	MVM
Hungary	Paks-3	PWR	473	Operating	1986	MVM
Hungary	Paks-4	PWR	473	Operating	1987	MVM
India	Kaiga-1	PHWR	202	Operating	2000	Nuclear Power Corp of India Ltd (NPCIL)
India	Kaiga-2	PHWR	202	Operating	2000	Nuclear Power Corp of India Ltd (NPCIL)
India	Kaiga-3	PHWR	202	Operating	2007	Nuclear Power Corp of India Ltd (NPCIL)
India	Kaiga-4	PHWR	202	Under construction		Nuclear Power Corp of India Ltd (NPCIL)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
India	Kaiga-5	PWR		Planned		Nuclear Power Corp of India Ltd (NPCIL)
India	Kaiga-6	PWR		Planned		Nuclear Power Corp of India Ltd (NPCIL)
India	Kakrapar-1	PHWR	202	Operating	1993	Nuclear Power Corp of India Ltd (NPCIL)
India	Kakrapar-2	PHWR	202	Operating	1995	Nuclear Power Corp of India Ltd (NPCIL)
India	Kakrapar-3	PHWR	700	Under construction		Nuclear Power Corp of India Ltd (NPCIL)
India	Kakrapar-4	PHWR	700	Under construction		Nuclear Power Corp of India Ltd (NPCIL)
India	Kalpakkam (PFBR)	FBR	440	Under construction		Nuclear Power Corp of India Ltd (NPCIL)
India	Kalpakkam-1 (Madras-1 / MAPS1)	PHWR	150	Operating	1984	Nuclear Power Corp of India Ltd (NPCIL)
India	Kalpakkam-2 (Madras-2 / MAPS2)	PHWR	150	Operating	1986	Nuclear Power Corp of India Ltd (NPCIL)
India	Kudankulam-1	PWR/VVER	950	Under construction		Nuclear Power Corp of India Ltd (NPCIL)
India	Kudankulam-2	PWR/VVER	936	Under construction		Nuclear Power Corp of India Ltd (NPCIL)
India	Narora-1	PHWR	202	Operating	1991	Nuclear Power Corp of India Ltd (NPCIL)
India	Narora-2	PHWR	202	Operating	1992	Nuclear Power Corp of India Ltd (NPCIL)
India	Rajasthan-1	PHWR	90	Operating	1973	Nuclear Power Corp of India Ltd (NPCIL)
India	Rajasthan-2	PHWR	187	Operating	1981	Nuclear Power Corp of India Ltd (NPCIL)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
India	Rajasthan-3	PHWR	202	Operating	2000	Nuclear Power Corp of India Ltd (NPCIL)
India	Rajasthan-4	PHWR	202	Operating	2000	Nuclear Power Corp of India Ltd (NPCIL)
India	Rajasthan-5	PHWR	202	Operating	2010	Nuclear Power Corp of India Ltd (NPCIL)
India	Rajasthan-6	PHWR	202	Under construction		Nuclear Power Corp of India Ltd (NPCIL)
India	Rajasthan-7	PHWR	640	Under construction		Nuclear Power Corp of India Ltd (NPCIL)
India	Rajasthan-8	PHWR	640	Under construction		Nuclear Power Corp of India Ltd (NPCIL)
India	Tarapur-1	BWR	150	Operating	1969	Nuclear Power Corp of India Ltd (NPCIL)
India	Tarapur-2	BWR	150	Operating	1969	Nuclear Power Corp of India Ltd (NPCIL)
India	Tarapur-3	PHWR	490	Operating	2006	Nuclear Power Corp of India Ltd (NPCIL)
India	Tarapur-4	PHWR	490	Operating	2005	Nuclear Power Corp of India Ltd (NPCIL)
Indonesia	Java-1 (Muria)		600	Planned		Indonesian National Nuclear Energy Agency (BATAN)
Iran	Bushehr-1	PWR/VVER	950	Under construction		Atomic Energy Organisation of Iran
Iran	Bushehr-2	PWR/VVER	950	Planned		Atomic Energy Organisation of Iran
Italy	Caorso	BWR	860	Shut down	1981	Societa Gestione Impianti Nucleari SpA (Sogin)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Italy	Cirene	HWLWR	40	Suspended indefinitely/Cancelled		Societa Gestione Impianti Nucleari SpA (Sogin)
Italy	Garigliano	BWR	150	Shut down	1964	Societa Gestione Impianti Nucleari SpA (Sogin)
Italy	Latina	GCR	153	Shut down	1964	Societa Gestione Impianti Nucleari SpA (Sogin)
Italy	Montalto di Castro-1	BWR	982	Suspended indefinitely/Cancelled		ENEL
Italy	Montalto di Castro-2	BWR	982	Suspended indefinitely/Cancelled		ENEL
Italy	Trino Vercellese	PWR	260	Shut down	1965	Societa Gestione Impianti Nucleari SpA (Sogin)
Japan	Fugen ATR	HWLWR	148	Shut down	1979	Japan Nuclear Cycle Development Institute (JNC)
Japan	Fukushima-Daiichi-1	BWR	439	Shut down	1971	Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daiichi-2	BWR	760	Shut down	1974	Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daiichi-3	BWR	760	Shut down	1976	Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daiichi-4	BWR	760	Shut down	1978	Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daiichi-5	BWR	760	Operating	1978	Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daiichi-6	BWR	1067	Operating	1979	Tokyo Electric Power Co (TEPCO)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Japan	Fukushima-Daiichi-7	ABWR	1325	Suspended indefinitely/Cancelled		Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daiichi-8	ABWR	1325	Suspended indefinitely/Cancelled		Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daini-1	BWR	1067	Operating	1982	Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daini-2	BWR	1067	Operating	1984	Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daini-3	BWR	1067	Operating	1985	Tokyo Electric Power Co (TEPCO)
Japan	Fukushima-Daini-4	BWR	1067	Operating	1987	Tokyo Electric Power Co (TEPCO)
Japan	Genkai-1	PWR	529	Operating	1975	Kyushu Electric Power Co
Japan	Genkai-2	PWR	529	Operating	1981	Kyushu Electric Power Co
Japan	Genkai-3	PWR	1127	Operating	1994	Kyushu Electric Power Co
Japan	Genkai-4	PWR	1127	Operating	1997	Kyushu Electric Power Co
Japan	Hamaoka-1	BWR	515	Shut down	1976	Chubu Electric Power Co
Japan	Hamaoka-2	BWR	806	Shut down	1978	Chubu Electric Power Co
Japan	Hamaoka-3	BWR	1056	Not operating	1987	Chubu Electric Power Co
Japan	Hamaoka-4	BWR	1092	Not operating	1993	Chubu Electric Power Co
Japan	Hamaoka-5	ABWR	1380	Not operating	2005	Chubu Electric Power Co
Japan	Hamaoka-6	ABWR	1380	Planned		
Japan	Higashi-Dori-1 (TEPCO)	ABWR	1320	Planned	2014	Tokyo Electric Power Co (TEPCO)
Japan	Higashi-Dori-1 (Tohoku)	BWR	1067	Operating	2005	Tohoku Electric Power Co

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Japan	Higashi-Dori-2 (TEPCO)	ABWR	1320	Planned	2016	Tokyo Electric Power Co (TEPCO)
Japan	Higashi-Dori-2 (Tohoku)	ABWR	1385	Planned		Tohoku Electric Power Co
Japan	Ikata-1	PWR	538	Operating	1977	Shikoku Electric Power Co
Japan	Ikata-2	PWR	538	Operating	1982	Shikoku Electric Power Co
Japan	Ikata-3	PWR	846	Operating	1994	Shikoku Electric Power Co
Japan	JPDR-II	BWR	10	Shut down	1965	Japan Atomic Energy Research Institute (JAERI)
Japan	Kaminoseki-1	ABWR	1320	Planned		Chugoku Electric Power Co
Japan	Kaminoseki-2	ABWR	1320	Planned		Chugoku Electric Power Co
Japan	Kashiwazaki Kariwa-1	BWR	1067	Operating	1985	Tokyo Electric Power Co (TEPCO)
Japan	Kashiwazaki Kariwa-2	BWR	1067	Operating	1990	Tokyo Electric Power Co (TEPCO)
Japan	Kashiwazaki Kariwa-3	BWR	1067	Operating	1993	Tokyo Electric Power Co (TEPCO)
Japan	Kashiwazaki Kariwa-4	BWR	1067	Operating	1994	Tokyo Electric Power Co (TEPCO)
Japan	Kashiwazaki Kariwa-5	BWR	1067	Operating	1990	Tokyo Electric Power Co (TEPCO)
Japan	Kashiwazaki Kariwa-6	ABWR	1315	Operating	1996	Tokyo Electric Power Co (TEPCO)
Japan	Kashiwazaki Kariwa-7	ABWR	1315	Operating	1997	Tokyo Electric Power Co (TEPCO)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Japan	Mihama-1	PWR	320	Operating	1970	Kansai Electric Power Co
Japan	Mihama-2	PWR	470	Operating	1972	Kansai Electric Power Co
Japan	Mihama-3	PWR	780	Operating	1976	Kansai Electric Power Co
Japan	Monju	FBR	246	Operating	1995	Japan Nuclear Cycle Development Institute (JNC)
Japan	Ohi-1	PWR	1120	Operating	1979	Kansai Electric Power Co
Japan	Ohi-2	PWR	1120	Operating	1979	Kansai Electric Power Co
Japan	Ohi-3	PWR	1127	Operating	1991	Kansai Electric Power Co
Japan	Ohi-4	PWR	1127	Operating	1993	Kansai Electric Power Co
Japan	Ohma	ABWR	1383	Under construction		Electric Power Development Co (J-Power)
Japan	Onagawa-1	BWR	498	Operating	1984	Tohoku Electric Power Co
Japan	Onagawa-2	BWR	796	Operating	1995	Tohoku Electric Power Co
Japan	Onagawa-3	BWR	796	Operating	2002	Tohoku Electric Power Co
Japan	Sendai-1	PWR	846	Operating	1984	Kyushu Electric Power Co
Japan	Sendai-2	PWR	846	Operating	1985	Kyushu Electric Power Co
Japan	Sendai-3	APWR	1538	Planned		
Japan	Shika-1	BWR	505	Operating	1993	Hokuriku Electric Power Co
Japan	Shika-2	ABWR	1358	Operating	2006	Hokuriku Electric Power Co
Japan	Shimane-1	BWR	439	Operating	1974	Chugoku Electric Power Co

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Japan	Shimane-2	BWR	789	Operating	1989	Chugoku Electric Power Co
Japan	Shimane-3	ABWR	1375	Under construction		Chugoku Electric Power Co
Japan	Takahama-1	PWR	780	Operating	1974	Kansai Electric Power Co
Japan	Takahama-2	PWR	780	Operating	1975	Kansai Electric Power Co
Japan	Takahama-3	PWR	830	Operating	1985	Kansai Electric Power Co
Japan	Takahama-4	PWR	830	Operating	1985	Kansai Electric Power Co
Japan	Tokai-1	GCR (Magnox)	159	Shut down	1966	Japan Atomic Power Co (JAPCO)
Japan	Tokai-2	BWR	1056	Operating	1978	Japan Atomic Power Co (JAPCO)
Japan	Tomari-1	PWR	550	Operating	1989	Hokkaido Electric Power Co
Japan	Tomari-2	PWR	550	Operating	1991	Hokkaido Electric Power Co
Japan	Tomari-3	PWR	912	Operating	2009	Hokkaido Electric Power Co
Japan	Tsuruga-1	BWR	341	Operating	1970	Japan Atomic Power Co (JAPCO)
Japan	Tsuruga-2	PWR	1115	Operating	1987	Japan Atomic Power Co (JAPCO)
Japan	Tsuruga-3	PWR	1500	Planned		Japan Atomic Power Co (JAPCO)
Japan	Tsuruga-4	PWR	1500	Planned		Japan Atomic Power Co (JAPCO)
Kazakhstan	BN-350 Aktau (Shevchenko)	LMFBR	70	Shut down	1973	National Atomic Company Kazatomprom
Korea DPR (North)	Sinpo-1	PWR	950	Construction suspended		State-owned

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Korea DPR (North)	Sinpo-2	PWR	950	Construction suspended		State-owned
Korea RO (South)	Kori-1	PWR	563	Operating	1978	Korea Electric Power Corp (Kepco)
Korea RO (South)	Kori-2	PWR	612	Operating	1983	Korea Electric Power Corp (Kepco)
Korea RO (South)	Kori-3	PWR	903	Operating	1985	Korea Electric Power Corp (Kepco)
Korea RO (South)	Kori-4	PWR	903	Operating	1986	Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin Ulchin 1	PWR	1350	Planned		Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin Ulchin 2	PWR	1350	Planned		Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin Wolsong-1	PWR	950	Under construction		Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin Wolsong-2	PWR	950	Under construction		Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin Wolsong-3	PWR	1350	Planned		Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin Wolsong-4	PWR	1350	Planned		Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin-Kori-1	PWR	1001	Operating	2011	Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin-Kori-2	PWR	1000	Under construction		Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin-Kori-3	APR	1350	Under construction		Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin-Kori-4	PWR	1400	Under construction		Korea Electric Power Corp (Kepco)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Korea RO (South)	Shin-Kori-5	PWR	1350	Planned		Korea Electric Power Corp (Kepco)
Korea RO (South)	Shin-Kori-6	PWR	1350	Planned		Korea Electric Power Corp (Kepco)
Korea RO (South)	Ulchin-1	PWR	920	Operating	1988	Korea Electric Power Corp (Kepco)
Korea RO (South)	Ulchin-2	PWR	920	Operating	1989	Korea Electric Power Corp (Kepco)
Korea RO (South)	Ulchin-3	PWR	960	Operating	1998	Korea Electric Power Corp (Kepco)
Korea RO (South)	Ulchin-4	PWR	960	Operating	1999	Korea Electric Power Corp (Kepco)
Korea RO (South)	Ulchin-5	PWR	950	Operating	2004	Korea Electric Power Corp (Kepco)
Korea RO (South)	Ulchin-6	PWR	950	Operating	2005	Korea Electric Power Corp (Kepco)
Korea RO (South)	Wolsong-1	PHWR	629	Operating	1983	Korea Electric Power Corp (Kepco)
Korea RO (South)	Wolsong-2	PHWR	700	Operating	1997	Korea Electric Power Corp (Kepco)
Korea RO (South)	Wolsong-3	PHWR	700	Operating	1998	Korea Electric Power Corp (Kepco)
Korea RO (South)	Wolsong-4	PHWR	700	Operating	1999	Korea Electric Power Corp (Kepco)
Korea RO (South)	Wolsong-5	PHWR	903	Planned	2011	Korea Electric Power Corp (Kepco)
Korea RO (South)	Wolsong-6	PHWR	903	Planned	2012	Korea Electric Power Corp (Kepco)
Korea RO (South)	Yonggwang-1	PWR	900	Operating	1986	Korea Electric Power Corp (Kepco)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Korea RO (South)	Yonggwang-2	PWR	900	Operating	1987	Korea Electric Power Corp (Kepco)
Korea RO (South)	Yonggwang-3	PWR	950	Operating	1995	Korea Electric Power Corp (Kepco)
Korea RO (South)	Yonggwang-4	PWR	950	Operating	1996	Korea Electric Power Corp (Kepco)
Korea RO (South)	Yonggwang-5	PWR	950	Operating	2002	Korea Electric Power Corp (Kepco)
Korea RO (South)	Yonggwang-6	PWR	950	Operating	2002	Korea Electric Power Corp (Kepco)
Lithuania	Ignalina-1	LWGR/RBMK	1185	Shut down	1985	Lithuanian Ministry of Economy
Lithuania	Ignalina-2	LWGR/RBMK	1185	Shut down	1987	Lithuanian Ministry of Economy
Lithuania	Visaginas-1			Planned		
Lithuania	Visaginas-2			Planned		
Mexico	Laguna Verde-1	BWR	800	Operating	1990	Comision Federal de Electricidad (CFEM)
Mexico	Laguna Verde-2	BWR	800	Operating	1995	Comision Federal de Electricidad (CFEM)
Netherlands	Borssele	PWR	452	Operating	1973	N.V. Elektriciteits-Produktiemaatschappij Zuid-Nederland (EPZ)
Netherlands	GKN Dodewaard	BWR	55	Shut down	1969	Gemeenschappelijke Kernenergiecentrale Nederland (GKN)
Pakistan	Chasma-1 (Chasnupp-1)	PWR	300	Operating	2000	Pakistan Atomic Energy Commission (PAEC)
Pakistan	Chasma-2 (Chasnupp-2)	PWR	300	Operating	2011	Pakistan Atomic Energy Commission (PAEC)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Pakistan	Chasma-3 (Chasnupp-3)	PWR	315	Under Construction		Pakistan Atomic Energy Commission (PAEC)
Pakistan	Karachi-1 (Kanupp-1)	PHWR	125	Operating	1972	Pakistan Atomic Energy Commission (PAEC)
Philippines	PNPP-1 (Batan)	PWR	620	Suspended indefinitely/Cancelled		National Power Corp (Napocor)
Poland	Zarnowiec-1	PWR/VVER	410	Suspended indefinitely/Cancelled		ZNPP
Poland	Zarnowiec-2	PWR/VVER	410	Suspended indefinitely/Cancelled		ZNPP
Poland	Zarnowiec-3	PWR/VVER	410	Suspended indefinitely/Cancelled		ZNPP
Poland	Zarnowiec-4	PWR/VVER	410	Suspended indefinitely/Cancelled		ZNPP
Romania	Cernavoda-1	PHWR/CANDU	655	Operating	1996	RENEL
Romania	Cernavoda-2	PHWR	650	Operating	2007	RENEL
Romania	Cernavoda-3	PHWR	630	Planned		RENEL
Romania	Cernavoda-4	PHWR	630	Construction suspended		RENEL
Romania	Cernavoda-5	PHWR	630	Construction suspended		RENEL
Russian Federation	Akademik Lomonosov 1 (Vilyuchinsk)	PWR	32	Under construction		JSC
Russian Federation	Akademik Lomonosov 2 (Vilyuchinsk)	PWR	32	Under construction		JSC
Russian Federation	Balakovo-1	PWR/VVER	950	Operating	1986	Rosenergoatom
Russian Federation	Balakovo-2	PWR/VVER	950	Operating	1988	Rosenergoatom

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Russian Federation	Balakovo-3	PWR/VVER	950	Operating	1989	Rosenergoatom
Russian Federation	Balakovo-4	PWR/VVER	950	Operating	1993	Rosenergoatom
Russian Federation	Balakovo-5	PWR/VVER	950	Construction suspended		Rosenergoatom
Russian Federation	Balakovo-6	PWR/VVER	950	Construction suspended	2011	Rosenergoatom
Russian Federation	Beloyarsk-1	LWGR/RBMK	102	Shut down	1964	Ministry of Atomic Energy and Industry (MAEI)
Russian Federation	Beloyarsk-2	LWGR/RBMK	170	Shut down	1969	Ministry of Atomic Energy and Industry (MAEI)
Russian Federation	Beloyarsk-3	FBR	560	Operating	1981	Rosenergoatom
Russian Federation	Beloyarsk-4	FBR	750	Under construction		Rosenergoatom
Russian Federation	Beloyarsk-5	FBR	300	Planned		
Russian Federation	Bilibino 1	LWGR/EGP	12	Operating	1970	Rosenergoatom
Russian Federation	Bilibino 2	LWGR/EGP	12	Operating	1975	Rosenergoatom
Russian Federation	Bilibino 3	LWGR/EGP	12	Operating	1976	Rosenergoatom
Russian Federation	Bilibino 4	LWGR/EGP	12	Operating	1977	Rosenergoatom
Russian Federation	Gorky-1	BWR	500	Suspended indefinitely/Cancelled		Rosenergoatom

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Russian Federation	Gorky-2	BWR	500	Suspended indefinitely/Cancelled		Rosenergoatom
Russian Federation	Kalinin-1	PWR/VVER	950	Operating	1985	Rosenergoatom
Russian Federation	Kalinin-2	PWR/VVER	950	Operating	1987	Rosenergoatom
Russian Federation	Kalinin-3	PWR/VVER	950	Operating	2004	Rosenergoatom
Russian Federation	Kalinin-4	PWR/VVER	950	Under construction		Rosenergoatom
Russian Federation	Kola-1	PWR/VVER	411	Operating	1973	Rosenergoatom
Russian Federation	Kola-2	PWR/VVER	411	Operating	1975	Rosenergoatom
Russian Federation	Kola-3	PWR/VVER	411	Operating	1982	Rosenergoatom
Russian Federation	Kola-4	PWR/VVER	411	Operating	1984	Rosenergoatom
Russian Federation	Kursk-1	LWGR/RBMK	925	Operating	1977	Rosenergoatom
Russian Federation	Kursk-2	LWGR/RBMK	925	Operating	1979	Rosenergoatom
Russian Federation	Kursk-3	LWGR/RBMK	925	Operating	1984	Rosenergoatom
Russian Federation	Kursk-4	LWGR/RBMK	925	Operating	1986	Rosenergoatom
Russian Federation	Kursk-5	LWGR/RBMK	925	Construction suspended		Rosenergoatom
Russian Federation	Leningrad II-1	PWR/VVER	1200	Under construction		Rosenergoatom

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Russian Federation	Leningrad II-2	PWR	1200	Under construction		Rosenergoatom
Russian Federation	Leningrad-1	LWGR/RBMK	925	Operating	1974	Leningrad NPP
Russian Federation	Leningrad-2	LWGR/RBMK	925	Operating	1976	Leningrad NPP
Russian Federation	Leningrad-3	LWGR/RBMK	925	Operating	1980	Leningrad NPP
Russian Federation	Leningrad-4	LWGR/RBMK	925	Operating	1981	Leningrad NPP
Russian Federation	Novo Melekes (VK50)	LWGR/RBMK	65	Shut down	1965	Ministry of Atomic Energy and Industry (MAEI)
Russian Federation	Novovoronezh II-1	PWR/VVER	1200	Under construction		
Russian Federation	Novovoronezh II-2	PWR/VVER	1200	Under construction		
Russian Federation	Novovoronezh-1	PWR/VVER	196	Shut down	1969	Rosenergoatom
Russian Federation	Novovoronezh-2	PWR/VVER	336	Shut down	1970	Rosenergoatom
Russian Federation	Novovoronezh-3	PWR/VVER	385	Operating	1972	Rosenergoatom
Russian Federation	Novovoronezh-4	PWR/VVER	385	Operating	1973	Rosenergoatom
Russian Federation	Novovoronezh-5	PWR/VVER	950	Operating	1981	Rosenergoatom
Russian Federation	Obninsk APS (Prototype)	LWGR	5	Shut down	1954	Minatom
Russian Federation	Rostov-1 (Volgodonsk-1)	PWR/VVER	950	Operating	2000	Rosenergoatom

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Russian Federation	Rostov-2 (Volgodonsk-2)	PWR/VVER	950	Operating		Rosenergoatom
Russian Federation	Rostov-3 (Volgodonsk-3)	PWR/VVER	950	Under construction		Rosenergoatom
Russian Federation	Rostov-4 (Volgodonsk-4)	PWR	950	Under construction	2017	Rosenergoatom
Russian Federation	Smolensk-1	LWGR/RBMK	925	Operating	1983	Rosenergoatom
Russian Federation	Smolensk-2	LWGR/RBMK	925	Operating	1985	Rosenergoatom
Russian Federation	Smolensk-3	LWGR/RBMK	925	Operating	1990	Rosenergoatom
Russian Federation	Smolensk-4	LWGR/RBMK	925	Construction suspended	2012	Rosenergoatom
Russian Federation	South Urals-1	PWR/VVER	950	Suspended indefinitely/Cancelled	2016	Rosenergoatom
Russian Federation	South Urals-2	PWR/VVER	950	Suspended indefinitely/Cancelled	2019	Rosenergoatom
Slovak Republic	Bohunice A-1	HWGCR	107	Shut down	1972	SEP
Slovak Republic	Bohunice-1	PWR/VVER	408	Shut down	1980	Slovak Energy Board
Slovak Republic	Bohunice-2	PWR/VVER	408	Shut down	1981	Slovak Energy Board
Slovak Republic	Bohunice-3	PWR/VVER	408	Operating	1985	Slovak Energy Board
Slovak Republic	Bohunice-4	PWR/VVER	408	Operating	1985	Slovak Energy Board
Slovak Republic	Mochovce-1	PWR/VVER	420	Operating	1998	Slovak Energy Board
Slovak Republic	Mochovce-2	PWR/VVER	420	Operating	2000	Slovak Energy Board
Slovak Republic	Mochovce-3	PWR/VVER	420	Under construction		Slovak Energy Board
Slovak Republic	Mochovce-4	PWR/VVER	420	Under construction		Slovak Energy Board
Slovenia	Krsko	PWR	676	Operating	1983	Nuklearna Elektrarna Krsko (NEK)
South Africa	Koeberg-1	PWR	921	Operating	1984	Eskom

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
South Africa	Koeberg-2	PWR	921	Operating	1985	Eskom
Spain	Almaraz-1	PWR	947	Operating	1983	Centrales Nucleares Almaraz-Trillo
Spain	Almaraz-2	PWR	950	Operating	1984	Centrales Nucleares Almaraz-Trillo
Spain	Asco-1	PWR	996	Operating	1984	Endesa
Spain	Asco-2	PWR	992	Operating	1986	Endesa
Spain	Cofrentes	BWR	1063	Operating	1985	Iberdrola S.A.
Spain	Jose Cabrera-1 (Zorita)	PWR	142	Shut down	1969	Union Fenosa Generation S.A.
Spain	Lemoniz-1	PWR	902	Suspended indefinitely/Cancelled		Iberduer
Spain	Lemoniz-2	PWR	902	Suspended indefinitely/Cancelled		Iberduer
Spain	Santa Maria de Garona	BWR	446	Operating	1971	Nuclenor S.A.
Spain	Santillan-1	BWR	950	Suspended indefinitely/Cancelled		Electricidad de Viesgo (EdV)
Spain	Sayago-1	PWR	1034	Suspended indefinitely/Cancelled		Iberduer
Spain	Trillo-1	PWR	1003	Operating	1988	Centrales Nucleares Almaraz-Trillo
Spain	Vandellos-1	GCR	480	Shut down	1972	Hifrensa
Spain	Vandellos-2	PWR	1045	Operating	1988	Asociacion Nuclear Asco-Vandellos A.I.E.
Sweden	AGESTA	PHWR	10	Shut down	1964	Barsebäck Kraft AB
Sweden	Barsebaeck-1	BWR	602	Shut down	1975	Sydkraft AB/Barseback Kraft
Sweden	Barsebaeck-2	BWR	602	Shut down	1977	Barsebaeck Kraft AB
Sweden	Forsmark-1	BWR	968	Operating	1980	Forsmark Kraftgrupp AB
Sweden	Forsmark-2	BWR	964	Operating	1981	Forsmark Kraftgrupp AB

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Sweden	Forsmark-3	BWR	1155	Operating	1985	Forsmark Kraftgrupp AB
Sweden	Marviken		140	Construction suspended		Swedish State Power Board
Sweden	Oskarshamn-1	BWR	467	Operating	1972	OKG Aktiebolag
Sweden	Oskarshamn-2	BWR	602	Operating	1975	OKG Aktiebolag
Sweden	Oskarshamn-3	BWR	1400	Operating	1985	OKG Aktiebolag
Sweden	Ringhals-1	BWR	840	Operating	1976	Swedish State Power Board
Sweden	Ringhals-2	PWR	870	Operating	1975	Swedish State Power Board
Sweden	Ringhals-3	PWR	920	Operating	1981	Swedish State Power Board
Sweden	Ringhals-4	PWR	915	Operating	1983	Swedish State Power Board
Switzerland	Beznau-1	PWR	365	Operating	1969	Nordostschweizerische Kraftwerke (NOK)
Switzerland	Beznau-2	PWR	365	Operating	1971	Nordostschweizerische Kraftwerke (NOK)
Switzerland	Goesgen	PWR	970	Operating	1979	Kernkraftwerk
Switzerland	Leibstadt	BWR	1165	Operating	1984	Kernkraft Leibstadt AG (KKL)
Switzerland	Lucens CNL	HWGCR	9	Shut down	1968	SNA/COS
Switzerland	Muehleberg	BWR	355	Operating	1972	BKW Energie AG
Taiwan	Chin Shan-1	BWR	604	Operating	1978	Taiwan Power Co
Taiwan	Chin Shan-2	BWR	604	Operating	1979	Taiwan Power Co
Taiwan	Kuosheng-1	BWR	948	Operating	1981	Taiwan Power Co
Taiwan	Kuosheng-2	BWR	948	Operating	1983	Taiwan Power Co
Taiwan	Lungmen-1	ABWR	1300	Under construction		Taiwan Power Co
Taiwan	Lungmen-2	ABWR	1300	Under construction		Taiwan Power Co

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Taiwan	Maanshan-1	PWR	890	Operating	1984	Taiwan Power Co
Taiwan	Maanshan-2	PWR	890	Operating	1985	Taiwan Power Co
Turkey	Akkuyu	PWR	1200	Planned		
Ukraine	Aktash-1	PWR	950	Suspended indefinitely/Cancelled		Energoatom
Ukraine	Aktash-2	PWR	950	Suspended indefinitely/Cancelled		Energoatom
Ukraine	Chernobyl-1	LWGR/RBMK	925	Shut down	1978	Energoatom
Ukraine	Chernobyl-2	LWGR/RBMK	925	Shut down	1979	Energoatom
Ukraine	Chernobyl-3	LWGR/RBMK	925	Shut down	1982	Energoatom
Ukraine	Chernobyl-4	LWGR/RBMK	925	Shut down	1984	Energoatom
Ukraine	Chernobyl-5	LWGR/RBMK	950	Suspended indefinitely/Cancelled		Energoatom
Ukraine	Chernobyl-6	LWGR/RBMK	950	Suspended indefinitely/Cancelled		Energoatom
Ukraine	Kharkov-1	PWR/VVER	900	Construction suspended		Energoatom
Ukraine	Khmelnitski-1	PWR/VVER	950	Operating	1988	Energoatom
Ukraine	Khmelnitski-2	PWR/VVER	950	Operating	2004	Energoatom
Ukraine	Khmelnitski-3	PWR/VVER	950	Construction suspended		Energoatom
Ukraine	Khmelnitski-4	PWR/VVER	950	Construction suspended		Energoatom
Ukraine	Odessa-1	PWR/VVER	900	Construction suspended		Energoatom
Ukraine	Odessa-2	PWR/VVER	900	Construction suspended		Energoatom
Ukraine	Rovno-1	PWR/VVER	402	Operating	1981	Energoatom
Ukraine	Rovno-2	PWR/VVER	416	Operating	1982	Energoatom
Ukraine	Rovno-3	PWR/VVER	950	Operating	1987	Energoatom

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
Ukraine	Rovno-4	PWR/VVER	950	Operating		Energoatom
Ukraine	South Ukraine-1	PWR/VVER	950	Operating	1983	Energoatom
Ukraine	South Ukraine-2	PWR/VVER	950	Operating	1985	Energoatom
Ukraine	South Ukraine-3	PWR/VVER	950	Operating	1989	Energoatom
Ukraine	South Ukraine-4	PWR/VVER	950	Construction suspended		Energoatom
Ukraine	Zaporozhe-1	PWR/VVER	950	Operating	1985	Energoatom
Ukraine	Zaporozhe-2	PWR/VVER	950	Operating	1986	Energoatom
Ukraine	Zaporozhe-3	PWR/VVER	950	Operating	1987	Energoatom
Ukraine	Zaporozhe-4	PWR/VVER	950	Operating	1988	Energoatom
Ukraine	Zaporozhe-5	PWR/VVER	950	Operating	1989	Energoatom
Ukraine	Zaporozhe-6	PWR/VVER	950	Operating	1996	Energoatom
United Arab Emirates	Braka-1	PWR	1400	Planned		Emirates Nuclear Energy Corporation
United Arab Emirates	Braka-2	PWR	1400	Planned		Emirates Nuclear Energy Corporation
United Arab Emirates	Braka-3	PWR	1400	Planned		Emirates Nuclear Energy Corporation
United Arab Emirates	Braka-4	PWR	1400	Planned		Emirates Nuclear Energy Corporation
United Kingdom	Berkeley-1	GCR (Magnox)	138	Shut down	1962	Nuclear Decommissioning Authority (NDA)
United Kingdom	Berkeley-2	GCR (Magnox)	138	Shut down	1962	Nuclear Decommissioning Authority (NDA)
United Kingdom	Bradwell Unit A	GCR (Magnox)	123	Shut down	1962	Nuclear Decommissioning Authority (NDA)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United Kingdom	Bradwell Unit B	GCR (Magnox)	123	Shut down	1962	Nuclear Decommissioning Authority (NDA)
United Kingdom	Calder Hall-1	GCR (Magnox)	50	Shut down	1956	Nuclear Decommissioning Authority (NDA)
United Kingdom	Calder Hall-2	GCR (Magnox)	50	Shut down	1957	Nuclear Decommissioning Authority (NDA)
United Kingdom	Calder Hall-3	GCR (Magnox)	50	Shut down	1958	Nuclear Decommissioning Authority (NDA)
United Kingdom	Calder Hall-4	GCR (Magnox)	50	Shut down	1959	Nuclear Decommissioning Authority (NDA)
United Kingdom	Chapelcross-1	GCR (Magnox)	49	Shut down	1959	Nuclear Decommissioning Authority (NDA)
United Kingdom	Chapelcross-2	GCR (Magnox)	49	Shut down	1959	Nuclear Decommissioning Authority (NDA)
United Kingdom	Chapelcross-3	GCR (Magnox)	49	Shut down	1959	Nuclear Decommissioning Authority (NDA)
United Kingdom	Chapelcross-4	GCR (Magnox)	49	Shut down	1960	Nuclear Decommissioning Authority (NDA)
United Kingdom	Dounreay DFR	FBR	14	Shut down	1962	UK Atomic Energy Authority (UKAEA)
United Kingdom	Dounreay PFR	FBR	250	Shut down	1976	UK Atomic Energy Authority (UKAEA)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United Kingdom	Dungeness-A1	GCR (Magnox)	225	Shut down	1965	Nuclear Decommissioning Authority (NDA)
United Kingdom	Dungeness-A2	GCR (Magnox)	225	Shut down	1965	Nuclear Decommissioning Authority (NDA)
United Kingdom	Dungeness-B1	AGR	555	Operating	1989	Electricite de France (EdF)
United Kingdom	Dungeness-B2	AGR	555	Operating	1985	Electricite de France (EdF)
United Kingdom	Hartlepool-1	AGR	605	Operating	1989	Electricite de France (EdF)
United Kingdom	Hartlepool-2	AGR	605	Operating	1989	Electricite de France (EdF)
United Kingdom	Heysham-A1	AGR	575	Operating	1989	Electricite de France (EdF)
United Kingdom	Heysham-A2	AGR	575	Operating	1989	Electricite de France (EdF)
United Kingdom	Heysham-B1	AGR	625	Operating	1989	Electricite de France (EdF)
United Kingdom	Heysham-B2	AGR	625	Operating	1989	Electricite de France (EdF)
United Kingdom	Hinkley Point-A1	GCR (Magnox)	235	Shut down	1965	Nuclear Decommissioning Authority (NDA)
United Kingdom	Hinkley Point-A2	GCR (Magnox)	235	Shut down	1965	Nuclear Decommissioning Authority (NDA)
United Kingdom	Hinkley Point-B1	AGR	610	Operating	1978	Electricite de France (EdF)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United Kingdom	Hinkley Point-B2	AGR	610	Operating	1976	Electricite de France (EdF)
United Kingdom	Hinkley Point-C1	PWR	1650	Planned		Electricite de France (EdF)
United Kingdom	Hinkley Point-C2	PWR	1650	Planned		Electricite de France (EdF)
United Kingdom	Hunterston-A1	GCR (Magnox)	160	Shut down	1964	Nuclear Decommissioning Authority (NDA)
United Kingdom	Hunterston-A2	GCR (Magnox)	160	Shut down	1964	Nuclear Decommissioning Authority (NDA)
United Kingdom	Hunterston-B1	AGR	595	Operating	1976	Electricite de France (EdF)
United Kingdom	Hunterston-B2	AGR	595	Operating	1977	Electricite de France (EdF)
United Kingdom	Oldbury-1	GCR (Magnox)	217	Operating	1967	Nuclear Decommissioning Authority (NDA)
United Kingdom	Oldbury-2	GCR (Magnox)	217	Shut down	1968	Nuclear Decommissioning Authority (NDA)
United Kingdom	Sizewell-A1	GCR (Magnox)	210	Shut down	1966	Nuclear Decommissioning Authority (NDA)
United Kingdom	Sizewell-A2	GCR (Magnox)	210	Shut down	1966	Nuclear Decommissioning Authority (NDA)
United Kingdom	Sizewell-B	PWR	1188	Operating	1995	Electricite de France (EdF)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United Kingdom	Sizewell-C1	PWR	1650	Planned		Electricite de France (EdF)
United Kingdom	Sizewell-C2	PWR	1650	Planned		Electricite de France (EdF)
United Kingdom	Torness unit A	AGR	625	Operating	1988	Electricite de France (EdF)
United Kingdom	Torness unit B	AGR	625	Operating	1989	Electricite de France (EdF)
United Kingdom	Trawsfynydd-1	GCR (Magnox)	196	Shut down	1965	Nuclear Decommissioning Authority (NDA)
United Kingdom	Trawsfynydd-2	GCR (Magnox)	196	Shut down	1965	Nuclear Decommissioning Authority (NDA)
United Kingdom	Windscale WAGR	GCR (AGR)	32	Shut down	1963	UK Atomic Energy Authority (UKAEA)
United Kingdom	Winfrith SGHWR	SGHWR	92	Shut down	1968	UK Atomic Energy Authority (UKAEA)
United Kingdom	Wylfa-1	GCR (Magnox)	490	Operating	1971	Nuclear Decommissioning Authority (NDA)
United Kingdom	Wylfa-2	GCR (Magnox)	490	Operating	1972	Nuclear Decommissioning Authority (NDA)
United States	Allens Creek-2; Wallis, TX	BWR	1150	Suspended indefinitely/Cancelled		
United States	Argonne EBWR; Argonne, IL	BWR	5	Shut down	1956	US Department of Energy (DOE)
United States	Arkansas Nuclear One-1; Russellville, AK	PWR	836	Operating	1974	Entergy Nuclear

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United States	Arkansas Nuclear One-2; Russellville, AK	PWR	965	Operating	1980	Entergy Nuclear
United States	Bayside; Tampa Bay, FL	BWR	1000	Suspended indefinitely/Cancelled		Atlantic City Electric
United States	Beaver Valley-1; Shippingport, PA	PWR	810	Operating	1976	First Energy
United States	Beaver Valley-2; Shippingport, PA	PWR	833	Operating	1987	First Energy
United States	Bellefonte-1; Hollywood, AL	PWR	1213	Suspended indefinitely/Cancelled		Tennessee Valley Authority (TVA)
United States	Bellefonte-2; Hollywood, AL	PWR	1213	Suspended indefinitely/Cancelled		Tennessee Valley Authority (TVA)
United States	Big Rock Point; Charlevoix, MI	BWR	67	Shut down	1963	Consumers Energy
United States	Bonus (Demo); Rincón, Puerto Rico	BWR	17	Shut down		US Department of Energy (DOE)
United States	Braidwood-1; Braidwood, IL	PWR	1120	Operating	1988	Exelon Nuclear Co
United States	Braidwood-2; Braidwood, IL	PWR	1120	Operating	1988	Exelon Nuclear Co
United States	Browns Ferry-1; Decatur, AL	BWR	1065	Operating	1974	Tennessee Valley Authority (TVA)
United States	Browns Ferry-2; Decatur, AL	BWR	1118	Operating	1975	Tennessee Valley Authority (TVA)
United States	Browns Ferry-3; Decatur, AL	BWR	1118	Operating	1977	Tennessee Valley Authority (TVA)
United States	Brunswick-1; Southport, NC	BWR	820	Operating	1977	Progress Energy Corp
United States	Brunswick-2; Southport, NC	BWR	811	Operating	1975	Progress Energy Corp
United States	Byron-1; Byron, IL	PWR	1105	Operating	1985	Exelon Nuclear Co
United States	Byron-2; Byron, IL	PWR	1105	Operating	1987	Exelon Nuclear Co
United States	Callaway-1; Fulton, MO	PWR	1235	Operating	1984	Ameren
United States	Calvert Cliffs-1; Lusby, MD	PWR	825	Operating	1975	Constellation Energy
United States	Calvert Cliffs-2; Lusby, MD	PWR	825	Operating	1977	Constellation Energy
United States	Carolinas CVTR; Parr, SC	PHWR	17	Shut down	1963	CVNPA

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United States	Catawba-1; Clover, SC	PWR	1129	Operating	1985	Duke Power Co
United States	Catawba-2; Clover, SC	PWR	1129	Operating	1986	Duke Power Co
United States	Cherokee-1; Gafney, SC	PWR	1280	Construction suspended		Duke Power Co
United States	Cherokee-2; Gafney, SC	PWR	1280	Construction suspended		Duke Power Co
United States	Clinch River; Oak Ridge, TN	FBR	350	Suspended indefinitely/Cancelled		Tennessee Valley Authority (TVA)
United States	Clinton-1; Clinton, IL	BWR	930	Operating	1987	AmerGen Energy Co
United States	Columbia (WNP-2); Richland, WA	BWR	1150	Operating	1984	Energy Northwest
United States	Comanche Peak-1; Glen Rose, TX	PWR	1150	Operating	1990	TXU Electric Co
United States	Comanche Peak-2; Glen Rose, TX	PWR	1150	Operating	1993	TXU Electric Co
United States	Cooper; Brownville, NE	BWR	764	Operating	1974	Nebraska Public Power District (NPPD)
United States	Crystal River-3; Red Level, FL	PWR	868	Operating	1977	Progress Energy Corp
United States	Crystal River-4; Red Level, FL	PWR	910	Suspended indefinitely/Cancelled		Progress Energy Corp
United States	Davis Besse-1; Oak Harbor, OH	PWR	877	Operating	1978	First Energy
United States	Diablo Canyon-1; Avila Beach, CA	PWR	1130	Operating	1985	Pacific Gas and Electric Co (PG&E)
United States	Diablo Canyon-2; Avila Beach, CA	PWR	1160	Operating	1986	Pacific Gas and Electric Co (PG&E)
United States	Donald Cook-1; Bridgman, MI	PWR	1020	Operating	1975	Indiana Michigan Power Co
United States	Donald Cook-2; Bridgman, MI	PWR	1108	Operating	1978	Indiana Michigan Power Co
United States	Dresden-1; Morris, IL	BWR	200	Shut down	1960	Commonwealth Edison (CommEd)
United States	Dresden-2; Morris, IL	BWR	912	Operating	1970	Exelon Nuclear Co
United States	Dresden-3; Morris, IL	BWR	794	Operating	1971	Exelon Nuclear Co

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United States	Duane Arnold-1; Palo, IA	BWR	600	Operating	1975	FPL Group
United States	EBR-II (test); INEL, ID	FBR	17	Shut down	1964	Argonne National Laboratory (ANL)
United States	Elk River; Elk River, MN	BWR	22	Shut down	1964	US Department of Energy (DOE)
United States	Enrico Fermi-1; Newport, MI	FBR	61	Shut down	1966	PRDC
United States	Enrico Fermi-2; Newport, MI	BWR	1139	Operating	1988	Detroit Edison Co
United States	Farley-1; Dothan, AL	PWR	828	Operating	1977	Alabama Power
United States	Farley-2; Dothan, AL	PWR	838	Operating	1981	Alabama Power
United States	FitzPatrick; Scriba, NY	BWR	780	Operating	1975	Entergy Nuclear
United States	Fort Calhoun-1; Fort Calhoun, NE	PWR	485	Operating	1974	Omaha Public Power District (OPPD)
United States	Fort St Vrain; Platteville, CO	HTGR	330	Shut down	1979	Public Service Co of Colorado (PSCC)
United States	Grand Gulf-1; Port Gibson, MS	BWR	1204	Operating	1985	Entergy Nuclear
United States	H B Robinson-2; Hartsville, SC	PWR	683	Operating	1971	Progress Energy Corp
United States	Haddam Neck; Haddam Neck, CT	PWR	590	Shut down	1968	Northern Utilities
United States	Hallam; Hallam, NE	Na-graphite	75	Shut down	1963	DOE/NPPD
United States	Hartsville-A1; Hartsville, TN	BWR	1206	Suspended indefinitely/Cancelled		Tennessee Valley Authority (TVA)
United States	Hartsville-A2; Hartsville, TN	BWR	1206	Suspended indefinitely/Cancelled		Tennessee Valley Authority (TVA)
United States	Hatch-1; Baxley, GA	BWR	863	Operating	1975	Southern Nuclear Operating Co
United States	Hatch-2; Baxley, GA	BWR	878	Operating	1979	Southern Nuclear Operating Co
United States	Hope Creek-1; Salem, NJ	BWR	1031	Operating	1986	Public Service Electric and Gas Co (PSEG)
United States	Humboldt Bay; Eureka, CA	BWR	63	Shut down	1963	Pacific Gas and Electric Co (PG&E)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United States	Indian Point-1; Buchanan, NY	PWR	255	Shut down	1962	Entergy Corp
United States	Indian Point-2; Buchanan, NY	PWR	975	Operating	1974	Entergy Nuclear
United States	Indian Point-3; Buchanan, NY	PWR	979	Operating	1976	Entergy Nuclear
United States	Kewaunee; Carlton, WI	PWR	556	Operating	1974	Dominion Resources
United States	LaCrosse; La Crosse, WI	BWR	50	Shut down	1969	DPC
United States	LaSalle-1; Seneca, IL	BWR	1078	Operating	1984	Exelon Nuclear Co
United States	LaSalle-2; Seneca, IL	BWR	1078	Operating	1984	Exelon Nuclear Co
United States	Limerick-1; Pottstown, PA	BWR	1200	Operating	1986	Exelon Nuclear Co
United States	Limerick-2; Pottstown, PA	BWR	1200	Operating	1990	Exelon Nuclear Co
United States	Maine Yankee; Wiscasset, ME	PWR	870	Shut down	1972	Maine Yankee Atomic Power Co
United States	McGuire-1; Cornelius, NC	PWR	1100	Operating	1981	Duke Power Co
United States	McGuire-2; Cornelius, NC	PWR	1100	Operating	1984	Duke Power Co
United States	Midland-1; Midland, MI	PWR	492	Suspended indefinitely/Cancelled		Consumers Power Corp
United States	Midland-2; Midland, MI	PWR	816	Suspended indefinitely/Cancelled		Consumers Power Corp
United States	Millstone-1; Waterford, CT	BWR	660	Shut down	1971	Northern Utilities
United States	Millstone-2; Waterford, CT	PWR	875	Operating	1975	Dominion Virginia Power
United States	Millstone-3; Waterford, CT	PWR	1152	Operating	1986	Dominion Virginia Power
United States	Monticello; Monticello, MN	BWR	593	Operating	1971	Xcel Energy
United States	Nine Mile Point-1; Scriba, NY	BWR	610	Operating	1969	Constellation Energy
United States	Nine Mile Point-2; Scriba, NY	BWR	1143	Operating	1988	Constellation Energy
United States	North Anna-1; Mineral, VA	PWR	925	Operating	1978	Dominion Virginia Power
United States	North Anna-2; Mineral, VA	PWR	917	Operating	1980	Dominion Virginia Power
United States	Oconee-1; Seneca, SC	PWR	846	Operating	1973	Duke Power Co
United States	Oconee-2; Seneca, SC	PWR	846	Operating	1974	Duke Power Co
United States	Oconee-3; Seneca, SC	PWR	846	Operating	1974	Duke Power Co
United States	Oyster Creek; Forked River, NJ	BWR	610	Operating	1969	AmerGen Energy Co

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United States	Palisades; South Haven, MI	PWR	789	Operating	1971	Consumers Energy
United States	Palo Verde-1; Wintersburg, AZ	PWR	1243	Operating	1986	Arizona Nuclear Power Project (ANPP)
United States	Palo Verde-2; Wintersburg, AZ	PWR	1243	Operating	1986	Arizona Nuclear Power Project (ANPP)
United States	Palo Verde-3; Wintersburg, AZ	PWR	1247	Operating	1988	Arizona Nuclear Power Project (ANPP)
United States	Pathfinder test reactor; Sioux Falls, SD	BWR	59	Shut down	1966	Northern States Power (NSP)
United States	Peach Bottom-1; Delta, PA	HTGR	40	Shut down	1967	PEC
United States	Peach Bottom-2; Delta, PA	BWR	1110	Operating	1974	Exelon Nuclear Co
United States	Peach Bottom-3; Delta, PA	BWR	1110	Operating	1974	Exelon Nuclear Co
United States	Perry-1; North Perry, OH	BWR	1265	Operating	1987	First Energy
United States	Perry-2; North Perry, OH	BWR	1205	Construction suspended		First Energy
United States	Pilgrim-1; Plymouth, MA	BWR	670	Operating	1972	Entergy Nuclear
United States	Piqua; Piqua, OH	OMR	11	Shut down	1963	US Department of Energy (DOE)
United States	Point Beach-1; Two Rivers, WI	PWR	485	Operating	1970	Wisconsin Electric Power Co
United States	Point Beach-2; Two Rivers, WI	PWR	485	Operating	1972	Wisconsin Electric Power Co
United States	Prairie Island-1; Red Wing, MN	PWR	530	Operating	1973	Xcel Energy
United States	Prairie Island-2; Red Wing, MN	PWR	530	Operating	1974	Xcel Energy
United States	Quad Cities-1; Cordova, IL	BWR	789	Operating	1973	Exelon Nuclear Co
United States	Quad Cities-2; Cordova, IL	BWR	789	Operating	1973	Exelon Nuclear Co
United States	R E Ginna; Ontario, NY	PWR	580	Operating	1970	Constellation Energy
United States	Rancho Seco; Clay Station, CA	PWR	913	Shut down	1975	Sacramento Municipal Utility District (SMUD)
United States	River Bend-1; St. Fracisville, LA	BWR	936	Operating	1986	Entergy Nuclear

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United States	Salem-1; Salem, NJ	PWR	1106	Operating	1977	Public Service Electric and Gas Co (PSEG)
United States	Salem-2; Salem, NJ	PWR	1106	Operating	1981	Public Service Electric and Gas Co (PSEG)
United States	San Onofre-1 (SONGS-1); San Clemente, CA	PWR	436	Shut down	1968	Southern Calfornia Ed.(80%), SDGE(20%)
United States	San Onofre-2; San Clemente, CA	PWR	1070	Operating	1983	Southern California Edison
United States	San Onofre-3; San Clemente, CA	PWR	1080	Operating	1984	Southern California Edison
United States	Santa Susana SRE; Simi Valley, CA	Na-graphite	8	Shut down	1957	DOE leased to SoCalEd
United States	Seabrook-1; Seabrook, NH	PWR	1162	Operating	1990	Florida Power and Light Co (FPL)
United States	Sequoyah-1; Soddy-Daisy, TN	PWR	1147	Operating	1981	Tennessee Valley Authority (TVA)
United States	Sequoyah-2; Soddy-Daisy, TN	PWR	1142	Operating	1982	Tennessee Valley Authority (TVA)
United States	Shearon Harris-1; New Hill, NC	PWR	860	Operating	1987	Progress Energy Corp
United States	Shippingport; Shippingport, PA	PWR	60	Shut down	1957	US Department of Energy (DOE)
United States	Shoreham; East Shoreham, NY	BWR	809	Shut down	1985	Long Island Power Authority
United States	South Texas-1; Palacios, TX	PWR	1268	Operating	1988	STP Nuclear Operating Co
United States	South Texas-2; Palacios, TX	PWR	1268	Operating	1989	STP Nuclear Operating Co
United States	St. Lucie-1; Hutchinson Island, FL	PWR	839	Operating	1976	Florida Power and Light Co (FPL)
United States	St. Lucie-2; Hutchinson Island, FL	PWR	839	Operating	1983	Florida Power and Light Co (FPL)

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United States	Surry-1; Gravel Neck, VA	PWR	810	Operating	1972	Dominion Virginia Power
United States	Surry-2; Gravel Neck, VA	PWR	815	Operating	1973	Dominion Virginia Power
United States	Susquehanna-1; Berwick, PA	BWR	1100	Operating	1983	Pennsylvania Power and Light Co (PP&L)
United States	Susquehanna-2; Berwick, PA	BWR	1103	Operating	1985	Pennsylvania Power and Light Co (PP&L)
United States	Three Mile Island-1; Londonderry Twp., PA	PWR	786	Operating	1974	AmerGen Energy Co
United States	Three Mile Island-2; Londonderry Twp., PA	PWR	905	Shut down	1978	Pen/JCPL/MetEd
United States	Trojan; Prescott, OR	PWR	1095	Shut down	1976	PortGE/PAcPL/EWEB
United States	Turkey Point-3; Florida City, FL	PWR	693	Operating	1972	Florida Power and Light Co (FPL)
United States	Turkey Point-4; Florida City, FL	PWR	693	Operating	1973	Florida Power and Light Co (FPL)
United States	Vallecitos VBWR; Alameda County, CA	BWR	5	Shut down	1957	General Electric
United States	Vermont Yankee; Vernon, VT	BWR	510	Operating	1972	Entergy Nuclear
United States	Virgil C Summer-1; Parr, SC	PWR	885	Operating	1984	South Carolina Electric and Gas Co
United States	Vogtle-1; Waynesboro, GA	PWR	1148	Operating	1987	Southern Nuclear Operating Co
United States	Vogtle-2; Waynesboro, GA	PWR	1149	Operating	1989	Southern Nuclear Operating Co
United States	Vogtle-3; Waynesboro, GA	PWR	1162	Planned		Southern Nuclear Operating Co
United States	Vogtle-4; Waynesboro, GA	PWR	1162	Planned		Southern Nuclear Operating Co
United States	Waterford-3; Taft, LA	PWR	1075	Operating	1985	Entergy Nuclear

Table 7 - World List of Nuclear Reactors (cont'd)

Location	Facility	Process	Capacity MWe net	Current Status	Start Year	Owner
United States	Watts Bar-1; Spring City, TN	PWR	1128	Operating	1996	Tennessee Valley Authority (TVA)
United States	Watts Bar-2; Spring City, TN	PWR	1177	Under construction		Tennessee Valley Authority (TVA)
United States	WNP-1; Richland, WA	PWR	1259	Construction suspended		WPPSS
United States	WNP-3; Richland, WA	PWR	1240	Construction suspended		WPPSS
United States	WNP-4; Richland, WA	PWR	1259	Construction suspended		WPPSS
United States	WNP-5; Richland, WA	PWR	1240	Construction suspended		WPPSS
United States	Wolf Creek; Burlington, KS	PWR	1135	Operating	1985	KGE/KCPL/KEPC
United States	Yankee Rowe; Rowe, MA	PWR	167	Shut down	1961	Yankee Atomic Electric Co
United States	Yellow Creek-1; Iuka, MS	PWR	1285	Suspended indefinitely/Cancelled		Tennessee Valley Authority (TVA)
United States	Yellow Creek-2; Iuka, MS	PWR	1285	Suspended indefinitely/Cancelled		Tennessee Valley Authority (TVA)
United States	Zion-1; Zion, IL	PWR	1040	Shut down	1973	Commonwealth Edison (CommEd)
United States	Zion-2; Zion, IL	PWR	1040	Shut down	1974	Commonwealth Edison (CommEd)

Notes:

1. Based on World Nuclear Association database search as of 8-5-11 on the web site: 'http://world-nuclear.org/NuclearDatabase/rdResults.aspx?id=27569
2. Data for United States - city and state data added primarily from Nuclear News March 2011

Table 8 - Fuel Cycle and Research Facility Data (based on EPRI 2010)

		EPRI 2010, Table 14-1						**Site Screening and Underground Research Laboratories**		
Country	Implementing Organization	GWe Net	No	%	Commercial Reprocessing Infrastructure	Pu-Recycle in LWRs as MOX	Fuel Cycle Policy	**Geologic Environments Considered from EPRI 2010**	**Research Laboratory Location from EPRI 2010**	**From Whipple 2010 Presentation to BRC**
Belgium	Belgian National Agency for Radioactive Waste and Fissile Materials (ONDRAF/NIRAS)	5.9	7	52	No	Yes	no final decision	Studies within a late 1970's EC program as well as an independent Belgian study identified only argillaceous rocks as being potentially suitable in Belgium, from which two main groups were recognized: hard rocks (shales) and poorly consolidated, plastic clay. Preliminary results from studies of the latter identified Boom Clay as being suitable.	A decision was made to construct an underground R&D facility (HADES) on and under the premises of SCK•CEN at Mol-Dessel. The initial construction phase started in 1980 and resulted in the completion of the R&D facility in 1983.	Mol (clay)
Canada	Nuclear Waste Management Organization (NWMO)	13	18	15	No	No	Once Through Fuel Cycle	A 1970's Commission recommended emplacement of used fuel in a deep underground repository within the Canadian Shield (i.e., crystalline rock).	AECL then moved towards constructing an underground facility for detailed in situ geological studies, also incorporating in its R&D program experiments and testing of emplacement techniques.	Pinawa (granite)
China	The Chinese National Nuclear Corporation (CNNC), the country's major (State-owned) nuclear utility	10	13	2	yes pilot scale with planned expansion to commercial	Planned	Modified Open Fuel Cycle with plans for fuel cycle closure	In the absence of specific regulations, China's siting program follows, in principle, the IAEA guidelines. Six locations, distributed throughout the country, were selected initially as the basis for initiating site selection.	Currently, the R&D work is focused only on a long-term feasibility study of a site located in northwest China, Beishan, in the Gobi desert. The host rock is primarily granite with low permeability and porosity and with low water outflow in the area.	None

Table 8 (cont'd)		EPRI 2010, Table 14-1						Site Screening and Underground Research Laboratories		
Country	Implementing Organization	GWe Net	No	%	Commercial Reprocessing Infrastructure	Pu-Recycle in LWRs as MOX	Fuel Cycle Policy	**Geologic Environments Considered from EPRI 2010**	**Research Laboratory Location from EPRI 2010**	**From Whipple 2010 Presentation to BRC**
Finland	Posiva Oy, an independent private company formed from two utility companies to plan, construct, and operate a geologic repository	2.7	4	33	`No	No	Once Through Fuel Cycle	In 1987, following review and recommendations by STUK and the government, TVO selected five areas for preliminary site characterization, which included many of the principal candidate rock types, all within the category of crystalline rock.	From 1993-2000, detailed characterization was carried out on four sites, including drilling deep boreholes, from which one site was identified for further detailed evaluation, on Olkiluoto, a small island to the southwest of Finland, and already hosting two nuclear power reactors.	Construction of ONKALO underground rock characterization facility in Eurajoki began in 2004 and is continuing (granite).
France	National Radioactive Waste Management Agency (ANDRA)	63	78	75	yes commercial scale for domestic and export	Yes	Modified Open Fuel Cycle with plans for fuel cycle closure	The 1991 Law required ANDRA to identify at least two sites that would be suitable for geologic disposal, one in clay and one in granite. From ANDRA's initial investigations, four sites were originally proposed for more detailed investigations. These were reduced to two sites, one in clay (Bure, east Paris Basin) and one in granite (Vienne, western France). The government approved continued research at the clay site but rejected the granite site based on technical concerns of the review commission.	The Bure site consists of a series of almost horizontal layers, with relatively simple geology, low tectonic activity, and low permeability. Homogeneity of the clay appears to be relatively high with few discontinuities. Geochemical conditions are reducing, with pH buffered by carbonate minerals.	Bure (argillite)

Table 8 (cont'd)		EPRI 2010, Table 14-1						Site Screening and Underground Research Laboratories		
Country	Implementing Organization	GWe Net	No	%	Commercial Reprocessing Infrastructure	Pu-Recycle in LWRs as MOX	Fuel Cycle Policy	**Geologic Environments Considered from EPRI 2010**	**Research Laboratory Location from EPRI 2010**	**From Whipple 2010 Presentation to BRC**
Germany	The Office for Radiation Protection (BfS), under the authority of the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU), is the implementer along with the Company for the Construction and Operation of Waste Repositories (DBE)	20	17	26	No	Yes	Once Through Fuel Cycle	Salt was recognized in the early 1960's as a potential geological medium for a HLW repository, and a large-scale study between 1964 and 1976 was devoted to the identification of potential salt structures in Germany. Criteria for suitable salt formations were formulated in 1964. Of 140 salt domes selected initially for evaluation, 23 were selected for further study. Further refinements in selection criteria reduced the number to 4 sites. After detailed site investigations involving the four candidate salt sites, Gorleben was eventually selected by Lower Saxony as a suitable site.	The Goreleben salt dome consists primarily of pure rock salt layers, which are largely solution-free. An impermeable salt barrier, approximately 600 m thick, extends across the planned emplacement area to the overburden. Further study was halted for political reasons, although the consensus of experts who have reviewed various documents on Gorleben is that the results "do not contradict the positive appraisal of the geological findings at the Gorleben site". More recently, Germany is considering the possibility of geologic disposal in formations other than salt, e.g. low permeability argillaceous rocks as an alternative.	Gorleben (salt)

Table 8 (cont'd)		EPRI 2010, Table 14-1						Site Screening and Underground Research Laboratories		
Country	Implementing Organization	GWe Net	No	%	Commercial Reprocessing Infrastructure	Pu-Recycle in LWRs as MOX	Fuel Cycle Policy	**Geologic Environments Considered from EPRI 2010**	**Research Laboratory Location from EPRI 2010**	**From Whipple 2010 Presentation to BRC**
Japan	Nuclear Waste Management Organization of Japan (NUMO), supported by research organizations: the Radioactive Waste Management Funding and Research Center (RWMC), and the Japanese Atomic Energy Agency (JAEA).	47	55	29	Yes, pilot scale with commercial scale imminent (although this may be reviewed as part of the analysis of the effects of the 2011 earthquake)	Yes	Modified Open Fuel Cycle with plans for fuel cycle closure	Site selection is a greater challenge in Japan than in most other countries, because of itsactive tectonic setting at the juncture of multiple convergent plate margins. Early site selection efforts were not successful. Site selection is now scheduled for the 2020's. To aid in the siting process, NUMO announced an overall procedure for selecting potential candidate sites, followed by the identification of siting factors to be provided to all municipalities in Japan.	To date, no community has volunteered. Meanwhile, research continues in two R&D facilities, one in crystalline rock (Mizunami) and the other in sedimentary rock (Horonobe).	Tono (granite) Mizunami (granite) Horonobe (sedimentary rock)
South Korea[1]	In Korea, the Radioactive Waste Management Company was created by Parliament in 2008. Ref. IAEA NEWMDB	18	21	32	No	No	Once through	The repository development process for HLW and SNF has not begun. (NWTRB 2011)	KAERI underground research tunnel (KURT) within the KAERI site has an access tunnel and two research modules. It was developed in 2003. (Kwon et al., 2006)	Korea Underground Research Tunnel (granite)

Table 8 (cont'd)		EPRI 2010, Table 14-1						**Site Screening and Underground Research Laboratories**		
Country	Implementing Organization	GWe Net	No	%	Commercial Reprocessing Infrastructure	Pu-Recycle in LWRs as MOX	Fuel Cycle Policy	**Geologic Environments Considered from EPRI 2010**	**Research Laboratory Location from EPRI 2010**	**From Whipple 2010 Presentation to BRC**
Spain	The Empresa Nacional de Residuos Radiactivos (ENRESA), a state-owned company, which reports to the Ministry of Energy.	7.4	8	17	No	No	Once Through Fuel Cycle	Site selection efforts started in 1998 and continued through 2001 until ENRESA issued its fifth report. These initial studies identified a number of deposits of clay (smectites) in different regions of Spain as being potentially suitable.	Additional research activities were carried out in a granite/U-bearing quartz vein system at El Berrocal, which has been studied as a natural analogue of a HLW repository.	None
Sweden	Swedish Nuclear Fuel and Waste Management Company (SKB)	9.4	10	35	No	Yes	Once Through Fuel Cycle	From six feasibility studies completed in 2000, SKB selected three sites (later reduced to two sites, Laxemar and Forsmark) for more detailed investigation. The initial site investigations were completed in 2006 with the publication of the SR-Can report. SKB formally compared the performance of a standard "KBS-3 type" repository design using site-specific data from Laxemar and Forsmark. Both sites were shown to comply with the regulator's 100,000-year risk criterion, and were accordingly judged to be suitable for selection as the repository site. SKB formally announced in 2009 its selection of the Forsmark site as the site for the deep geologic disposal of used fuel in Sweden.	As part of its research activities, SKB constructed the Äspö underground Hard Rock Laboratory between 1990 and 1995 and continues to carry out experiments and testing in this facility.	Äspö (granite)

Table 8 (cont'd)		EPRI 2010, Table 14-1						Site Screening and Underground Research Laboratories		
Country	Implementing Organization	GWe Net	No	%	Commercial Reprocessing Infrastructure	Pu-Recycle in LWRs as MOX	Fuel Cycle Policy	**Geologic Environments Considered from EPRI 2010**	**Research Laboratory Location from EPRI 2010**	**From Whipple 2010 Presentation to BRC**
Switzerland	National Cooperative for the Disposal of Radioactive Waste (NAGRA) (NWTRB 2011, and NAGRA 2002)	3.2	5	39	No	Yes	Modified Open Fuel Cycle with option for direct disposal	Three host-rock variants have been considered —either the crystalline basement or one of the two overlying, low-permeability sediment layers. Geological studies showed that the extent of accessible crystalline basement was much less than originally thought. Thus, only two relatively restricted areas remain for the selection of a possible site, each covering an area of about 50 km^2. With regard to sedimentary formations, NAGRA identified Opalinus Clay as the top priority and conducted a field program in the potential siting area.	Geological investigations have benefitted from two URL programs, at Grimsel in crystalline rock, and another at Mont Terri for clay studies.	Mont Terri (clay) and Grimsel (granite)
Taiwan	Taipower, the owner/operator for all the nuclear power plants, is a state-owned utility, with oversight by the Atomic Energy Council (AEC)	4.9	6	21	No	No	Once Through Fuel Cycle	Geological survey information obtained during an early study (late 1980's, early1990's) indicated that potential host rocks, including granite, thick shale and mudstone layers, exist at appropriate depths in Taiwan. The Spent Nuclear Fuel Final Disposal Plan approved by AEC in 2006 identified a five-stage process to select a suitable site, starting with regional investigations. Such geologic investigations are ongoing, including exploratory boreholes. This stage is expected to be completed in 2017 with the preparation and submission of a technical feasibility report.	The area currently under study is in a granite formation on Kinmen Island, west of the Taiwan Strait and close to mainland China.	(Not addressed)

Table 8 (cont'd)		EPRI 2010, Table 14-1						Site Screening and Underground Research Laboratories		
Country	Implementing Organization	GWe Net	No	%	Commercial Reprocessing Infrastructure	Pu-Recycle in LWRs as MOX	Fuel Cycle Policy	**Geologic Environments Considered from EPRI 2010**	**Research Laboratory Location from EPRI 2010**	**From Whipple 2010 Presentation to BRC**
United Kingdom	The Nuclear Decommissioning Authority (NDA), a non-departmental public body under the purview of the Department of Energy and Climate Change. (NWTRB 2011) NDA covers disposal and safe and secure interim storage of waste on civilian nuclear sites.	11	19	18	Yes commercial scale for domestic and export	No	No final decision, Once Through Fuel Cycle for LWRs likely	In the 1970's, geological investigations related to geologic disposal began in different areas throughout England, Wales and Scotland, with a view to identifying a suitable site for geologic disposal. Largely as a result of intensive public opposition, these geological investigations stopped in 1980. Since then, NDA has adopted three generalized geological host environments as a basis for exploring disposal concepts: strong, hard rocks; less strong, sedimentary rocks; and evaporates. With regard to the future implementation framework for site selection or site assessment, the Government is committed to an approach based on "voluntarism and partnership".		None

Notes

1 – Data on GWe, number of reactors, and percent of power generation by nuclear plants for South Korea was from the IAEA NEWMDB, Appendix B, and IAEA PRIS.

2 – This column represents information presented to the BRC and is for comparison with the EPRI 2010 data.

3.1 Argentina

- Argentina has two nuclear reactors generating nearly one-tenth of its electricity.
- Its first commercial nuclear power reactor began operating in 1974.
- Completion of the country's third reactor is expected by early 2012.

3.1.1 Radioactive waste management

The April 1997 National Law of Nuclear Activity assigns responsibility for radioactive waste management to the National Atomic Energy Commission (CNEA), and creates a special fund for the purpose. Operating plants pay into this.

Low and intermediate-level wastes including used fuel from research reactors are handled at CNEA's Ezeiza facility. Used fuel is stored at each power plant. There is some dry storage at Embalse.

CNEA is also responsible for plant decommissioning, which must be funded progressively by each operating plant.

In Argentina the following criteria are applied to Radioactive Waste Management:

- Allow for the withdrawal of radioactive material from regulatory control when on account of its activity concentration and/or total activity it may be released from regulatory control
- Authorize the planned and controlled discharge of liquid and gaseous radioactive materials that originate from the normal operation of a nuclear facility and which on account of their total radioactivity may be released into the environment.
- Treatment, conditioning and final disposal of radioactive waste, understanding that radioactive waste means materials that on account of their concentration of radioactivity and/or total radioactivity cannot be released into the environment.

3.2 Armenia

- Armenia has relied heavily on nuclear power since 1976.
- It has one reactor in operation and the government has approved a joint venture to build another by 2018.

Although Armenia has only one operating nuclear reactor, this unit supplied 39.4% of the total electricity produced in 2008.

3.2.1 Radioactive waste management

The spent nuclear fuel, before its transfer to the dry storage, is being kept in fuel pools (wet nuclear fuel storage). In 2000, the construction of the first stage of spent fuel dry storage was completed. The construction was commissioned by the French firm Framatom and financed by the French Government. The spent fuel dry storage facility has been put into operation, and all the transportation of spent fuel was performed according to the requirements of the license given by the ANRA (Armenian Nuclear Regulatory Authority). Now, all the volume of the storage is filled with the spent fuel. Construction of a second stage of the dry storage facility is under consideration. The final spent fuel and radwaste treatment and disposal concept will be developed and included in the ANPP Decommissioning Program.

3.3 Belgium

- Belgium has seven nuclear reactors generating more than half of its electricity.
- Belgium's first commercial nuclear power reactor began operating in 1974.
- There has been little government support for nuclear energy, but this is changing.

The current major developments in radioactive waste management in Belgium are mainly related to the return of vitrified high-level waste (from France), the selection of final radwaste disposal sites and R&D on disposal of various waste categories.

3.3.1 Radioactive waste management

The National Agency for Radioactive Waste and Enriched Fissile Materials – ONDRAF/NIRAS – is responsible for the management of all radioactive materials in the country, including transport, treatment, conditioning, storage and disposal. Its main facility is at the Mol-Dessel site, run by its subsidiary Belgoprocess. Its costs are passed on to the producers of radioactive waste, notably the power companies. Utilities pay a levy on each kWh of electricity sold, which goes into a decommissioning and waste management fund managed by Synatom.

A number of shipments of vitrified high-level waste from reprocessed Belgian fuel have taken place from La Hague in France. The wastes are stored at Dessel. However, following the 1993 political decision to suspend reprocessing activities, used fuel is currently stored at the nuclear power plants. Most of the country's high-level waste originates from the Eurochemic reprocessing plant.

In June 2006, the government decided that low-level and short-lived intermediate-level wastes would be disposed of in a surface repository at Desseli. The municipality of Mol had also been considered and expressed willingness for the facility to be there.

Research on deep geological disposal of long-lived intermediate-level and high-level wastes is underway and focuses on the clays at Mol. In 1980, construction of the Hades (High-activity disposal experimental site) underground research laboratory 225 m deep in the Boom clay commenced. The management and operation of Hades is carried out by the Economic Interest Grouping EURIDICE (European underground research infrastructure for disposal of radioactive waste in a clay environment), which was set up by ONDRAF/NIRAS and the Belgian Nuclear Research Centre (SCK.CEN). The main objective of EURIDICE is to carry out the PRACLAY (Preliminary demonstration test for clay disposal of highly radioactive waste) project, which aims to demonstrate the feasibility of disposing of radioactive waste in deep clay layers.

3.3.2 Decommissioning

Decommissioning activities are now well advanced at several early nuclear facilities. These include:

- The 40 MWt BR3 prototype PWR reactor which was started up in 1962 and closed down in 1987 is being decommissioned by SCK.CEN (see end of Research and development below).
- The Franco-Belgian Chooz A in France was closed in 1991 and is being decommissioned by EdF.
- The Eurochemic reprocessing plant ended reprocessing activities in 1974 and decommissioning by Belgoprocess began in 1989. Scheduled for completion in 2012, it will become the world's first reprocessing plant to be decommissioned.
- Decommissioning of Belgonucleaire's MOX fuel fabrication plant at Dessel is underway and expected to be completed by 2013.

3.4 Brazil

- Brazil has two nuclear reactors generating 3% of its electricity, and a third under construction.
- Its first commercial nuclear power reactor began operating in 1982.
- Four more large reactors are planned to come on line by 2025.

3.4.1 Radioactive waste management

The major source of radioactive waste produced in Brazil is the two nuclear power plants. The waste generated by the uranium mining and milling industrial complex, although significant in volume, is kept at the site, in a dam specially built for this purpose. The waste management policy takes into account both the accumulated and projected waste generated by the above mentioned facilities and the existing 3,500 cubic meters of Caesium-137 waste produced as a result of the decontamination work performed in Goiânia, following the 1987 accident that involved a 1,375 Curies teletherapy source.

The National Nuclear Energy Commission (Comissão Nacional de Energia Nuclear, CNEN) is responsible for management and disposal of radioactive wastes. Legislation in 2001 provides for repository site selection, construction and operation for low- and intermediate-level wastes. A long term solution for these is to be in place before Angra 3 is commissioned.

Used fuel is stored at Angra pending formulation of policy on reprocessing or direct disposal.

3.5 Bulgaria

- Bulgaria has two nuclear reactors generating about 35% of its electricity.
- There are proposals to restart two others, shut down under duress as a condition of Bulgaria joining the European Union.
- Bulgaria's first commercial nuclear power reactor began operating in 1974.
- Government commitment to the future of nuclear energy is strong and construction of a new nuclear plant is planned.

3.5.1 Radioactive waste management

The State Enterprise Radioactive Wastes (SE-RAW) is responsible for much of the waste management. Under a 2002 agreement, Bulgaria has been paying Russia US$ 620,000 per ton of used nuclear fuel repatriated for reprocessing in the Mayak plant at Ozersk, though some has also been sent to the Zheleznogorsk plant at Krasnoyarskn. Used fuel is initially stored in pools at each reactor, but in 1990 a pool-type storage facility was constructed at Kozloduy to take fuel from all the units. This was upgraded and a new license issued by the Bulgarian Nuclear Regulatory Agency (NRA) in 2001.

A new €49 million dry storage facility for 2800 VVER-440 used fuel assemblies has been built near this at Kozloduy, with finance from the Kozloduy International Decommissioning Support Fund administered by the European Bank for Reconstruction and Development. This Dry Spent Fuel Storage Facility (DSFSF) was being constructed by a joint venture partnership between Nukem Technologies and GNS. Later expansion to accommodate 8000 VVER-440 and 2500 VVER-1000 assemblies is envisaged. The facility, with capacity of 5200 fuel assemblies in 72 casks, was officially opened in May 2011. It will accommodate used fuel from Kozloduy's four closed VVER-440 units, currently in pool storage, and will be subsequently enlarged to receive casks with fuel from VVER-1000 units 5 and 6.

Also at Kozloduy is a low- and intermediate-level radioactive waste treatment and storage facility.

In mid-2005, the Council of Ministers resolved that a 50,000 cubic meter national near-surface low-level and intermediate-level waste disposal facility should be constructed by SE-RAW for operation in 2015. The National Repository for Disposal of Radioactive Waste (NRD RAW) will be paid for from the radioactive waste fund. In April 2009, SE-RAW awarded a €2.6 million three-year contract to a consortium comprising of Empresarios Agrupados Internacinal SA , VT Nuclear Services and ENPRO Consult of Bulgaria to project manage the facility. The consortium is responsible for site selection, design, safety assessment construction and commissioning of the facility.

A near-surface repository Novi Han, about 35km southeast of Sofia, is licensed for non-nuclear radioactive wastes.

Two national funds were created in 1992, one for the safe disposal of radioactive waste and one for the decommissioning of nuclear facilities, but these funds did not function properly until 1999. The funds are independent from the nuclear industry and managed by the government. The main contribution to the two funds comes from an electricity price levy specified by the Bulgarian Council of Ministers. The Kozloduy nuclear plant pays 3% of the price of its power into the waste management fund and a further 7.5% into the decommissioning fund.

3.5.2 Decommissioning

In addition to the national decommissioning fund, in June 2001 the Kozloduy International Decommissioning Support Fund (KIDSF) was established at the European Bank for Reconstruction and Development (EBRD) to finance decommissioning activities of Kozloduy 1-4 as well as support energy projects in the country. In 2009, almost €120 million worth of contracts were signed under the KIDSF, including a €22.5 million contract for Onet Technologies for the treatment of radioactive concentrates and a €30 million contract for a joint venture between Iberdrola Ingenieria y Construccion and Belgoprocess NV to supply a waste treatment and conditioning facility.

The licences for Kozloduy 1 & 2 were transferred to State Enterprise 'Radioactive Waste' (SERAW) by the Nuclear Regulatory Agency in October 2010, in anticipation of decommissioning work.

3.6 Canada

- About 15% of Canada's electricity comes from nuclear power, with 18 reactors in three provinces providing over 12,600 MWe of power capacity.
- Canada plans to expand its nuclear capacity over the next decade by building as many as nine new reactors.
- For many years Canada has been a leader in nuclear research and technology, exporting reactor systems developed in Canada as well as a high proportion of the world supply of radioisotopes used in medical diagnosis and cancer therapy

3.6.1 Radioactive waste storage and disposal

Canada's Nuclear Waste Management Organization (NWMO) was set up under the 2002 Nuclear Fuel Waste Act by the nuclear utilities operating in conjunction with AECL. Its mandate is to explore options for storage and disposal, to then make proposals to the government and to implement what is decided. NWMO, working with AECL, is also required to maintain trust funds for used fuel management and probable disposal. Less than 3000 tons of spent fuel per year from Candu reactors is involved.

3.6.2 High-level waste

For high-level wastes, in 2005 NWMO published three conceptual designs for the technical options specified in the Nuclear Fuel Waste Act, based on proven technologies. The first, reactor site extended storage (at seven sites), was found to be feasible, requiring only some further dry storage facilities to be built. The second, centralized extended storage is similar to systems already operating in 12 countries but is longer term. Dry storage is also preferred in this case, with two options on the surface and two below ground level. A deep geological repository is the third possibility, allowing later retrieval if required. It is most closely aligned with international consensus and had already been the subject of detailed scrutiny by the federal Environment Assessment Panel over three years in the 1990s, involving public hearings. This option, known as adaptive phased management, was the one recommended by NWMO and chosen by the government in June 2007. NWMO is now responsible for implementing it.

A deep geological depository involves burying nuclear waste 500 to 1000 meters deep in the stable rock of the Canadian Shield, the large formation that extends northward across central and eastern Canada. The waste would be placed below the water table in containers packed in bentonite clay. The waste may consist of used fuel bundles or solidified high-level waste from reprocessing, sealed in copper or titanium containers.

Early in 2007, NWMO stated that a final repository would probably be in Ontario, Quebec, New Brunswick or Saskatchewan, and host localities would need to volunteer for the role. The organization expects to have designed a siting process by the end of 2009 and to commence technical and socio-economic assessment of potential candidate sites by the end of 2012.

3.6.3 Low- and intermediate-level waste

The nuclear utilities and AECL remain responsible for low- and intermediate-level wastes, which are currently stored above ground.

Following a strong positive response to polling of local residents, Ontario Power Generation (OPG) in 2005 proceeded with plans to construct a Deep Geologic Repository for 200,000 cubic meters of its low- and intermediate-level wastes. The repository will be located 680 meters beneath OPG's Western Waste Management Facility, which it has operated since 1974. Environmental assessment and licensing has proceeded since, and in April 2011 OPG submitted its 12,500-page environmental assessment to CNSC. A construction license is expected in 2012, and operation from around 2018. Financing for the repository project is provided from the decommissioning fund established under the Ontario Nuclear Funds Agreement.

OPG is the owner and licensee of the repository; however, NWMO was contracted to manage development of it from the beginning of 2009.

The Western Waste Management Facility stores all the low- and intermediate-level nuclear waste from the operation of OPG's 20 nuclear reactors, including those leased to Bruce Power.

3.6.4 Legacy wastes

In June 2006 the Canadian government announced a five-year, C$520 million program to clean up legacy wastes from R&D on nuclear power and medical isotopes and military activities in the 1940s and early 1950s. The program covers clean-up of AECL contaminated lands, radioactive wastes and decommissioning old infrastructure which is the responsibility of the government. A large amount of low-level legacy waste from former radium and uranium refinery operations at Port Hope, Ontario, will be permanently emplaced in an above-ground repository.

3.6.5 Decommissioning

Three power reactors have been shut down and are being decommissioned: Gentilly 1, Douglas Point and Rolphton NPD – all owned by AECL. They were shut down in 1977, 1984 and 1987 respectively and are expected to be demolished in about 30 years. Gentilly 1 was a steam-generating heavy water reactor with vertical pressure tubes, light water coolant and heavy water moderation. It was not successful, and had only about 180 full-power days in six years operation. The other two were prototype Candu designs.

3.7 China

- Mainland China has 14 nuclear power reactors in operation, more than 25 under construction, and more about to start construction soon.
- Additional reactors are planned, including some of the world's most advanced, to give more than a ten-fold increase in nuclear capacity to at least 80 GWe by 2020, 200 GWe by 2030, and 400 GWe by 2050.
- China is rapidly becoming self-sufficient in reactor design and construction, as well as other aspects of the fuel cycle.

3.7.1 Radioactive waste management

In the absence of specific regulations, China's siting program follows, in principle, the IAEA guidelines. Six locations, distributed throughout the country, were selected initially as the basis for initiating site selection (EPRI 2010).

3.8 Czech Republic

- The Czech Republic has six nuclear reactors generating about one-third of its electricity.
- Its first commercial nuclear power reactor began operating in 1985.
- Government commitment to the future of nuclear energy is strong.

3.8.1 Radioactive waste management

There is no state policy on reprocessing and the decision is left to the operator (CEZ), which does not perceive it as being economic. However, the question remains open.

CEZ is fully responsible for storage and management of its used fuel until it is handed over to the state organization Radioactive Waste Repository Authority (RAWRA).

Used fuel is stored at each power plant. Originally, used fuel from Dukovany was sent to the interim storage facility at the Bohunice plant (now in Slovakia). The dissolution of Czechoslovakia in 1993 meant that this used fuel originating from Dukovany was stored in a different country, and therefore required repatriation. An interim dry storage facility with capacity of 600 t was built at Dukovany, and the plant's used fuel storage pools were reracked to increase capacity. The dry storage facility commenced operation in 1995 and since then another storage facility has been built there.

Re-racking of storage pools has also taken place at Temelin, and in 2009 construction began on an interim dry storage facility there. It is expected to commence operation in 2010. CEZ creates an internal financial reserve for long-term used fuel storage.

An interim storage facility for used research reactor fuel is located at the Rez nuclear research institute (see section below on Research and development).

At the beginning of 2000, ownership of the country's three repositories – Dukovany, Richard and Bratrstvi – were transferred to the state under the management of RAWRA. Waste from non-power applications is disposed of at the Richard and Bratrstvi repositoriesl. The Dukovany repository is the largest of the repositories and was built specifically for the disposal of low-level and intermediate-level radioactive waste generated during the operation of the Dukovany and Temelin nuclear plants. The 55,000 m3 storage volume provides enough space for the waste from both plants, even with their operational lifetimes extended to 40 years. Each of the repository's 112 vaults can accommodate about 1600 individual 200-litre drums. It began operation in 1995 and 15 of the vaults were full by the end of 2009.

Eventual provision of a high-level waste repository is the responsibility of (RAWRA). Selection of a candidate and a reserve site is scheduled for 2015, with construction start after 2050 and operation beginning in 2065. One possible site is at Skalka in southern Moravia. In the late 1990s, this site was considered for a central used fuel interim storage facility as an alternative to the Temelin storage facility and to the storage capacity expansion at Dukovany (beyond the 600 t facility)m. Under the Atomic Energy Act 2002, CEZ as nuclear plant operator is required to put aside funds for waste disposal, lodging these with the Czech National Bank. The rate is CZK 0.05 (€0.002) per kWh. The Act also requires that nuclear plants are decommissioned following the end of their operating lifetimes and CEZ is also progressively funding this. The adequacy of reserve funds for decommissioning is under the supervision of RAWRA.

3.9 Finland

- Finland has four nuclear reactors providing nearly 30% of its electricity.
- A fifth reactor is now under construction and two more are planned.
- Provisions for radioactive waste disposal are well advanced.

3.9.1 Radioactive waste management

Finland's nuclear waste management program was initiated in 1983, soon after the four reactors started commercial operation. The 1987 Nuclear Energy Act had final disposal as an option and set up the nuclear waste management fund under the Ministry of Trade and Industry. The 1994 amendment of the Act stipulates that wastes should be handled wholly in the country (the prior arrangement with Russia for Loviisa used fuel finished in 1996). Reactor decommissioning is the responsibility of the two power companies separately, and plans are updated every five years. Responsibility for nuclear wastes remains with the power companies until final disposal.

As of early 2008, over €1.6 billion had been accumulated in the State Nuclear Waste Management Fund from charges on generated electricity, which account for about 10% of nuclear electricity production costs. The charges are set annually by the government according to the assessed liabilities for each company and also cover decommissioning.

At Olkiluoto, surface pool storage for spent fuel has been in operation since 1987. This KPA facility has 1270 ton capacity and is designed to hold used fuel for about 50 years, pending deep geological disposal. An extension to the KPA facility is scheduled for 2011-2014.

At Loviisa, expanded interim storage pools required by expiry of the Russian arrangement to take back used fuel were commissioned in 2000.

TVO and Fortum are responsible for the management and disposal of their low- and intermediate-level operational wastes. An underground repository at Olkiluoto for low- and intermediate-level operational wastes has been in operation since 1992. It is designed to be expanded to take eventual decommissioning wastes. A similar facility at Loviisa was commissioned in 1997.

3.9.2 Used fuel disposal

The final disposal of used nuclear fuel is managed by Posiva Oy, which was set up in 1995 as a joint venture company – 60% TVO and 40% Fortum. It has well advanced plans for a deep geological repository for encapsulated used fuel at the Olkiluoto Island in Eurajoki, some 400 meters down in 2 billion-year-old igneous rock. Posiva's plans do not include accommodation for used fuel from Fennovoima's new plant.

Site selection and environmental impact assessment work was carried out following the Government’s 1983 policy decision on used nuclear fuel. Four locations were investigated by Posiva in some detail – all were technically suitable and were covered in Posiva's environmental impact statement for the final repository. In 1999, Posiva applied for a decision in principle for the final disposal facility to be sited at Eurajoki. The decision in principle was issued by the Government at the end of 2000 and ratified by Parliament by a 159 to 3 vote in May 2001. The proposal has strong local community support, and the Eurajoki Council – which had the right to veto the decision – voted 20:7 for it.

Construction on the ONKALO underground rock characterization facility commenced in 2004 at the Eurajoki site. Research to verify the site selection has been carried out at ONKALO since the beginning of its construction. This will then become the repository site. A construction license for the final repository and the encapsulation plant will be sought about 2012. The operating license application is expected in 2018, with a view to operation from 2020. Current plans envisage the sealing of the repository in 2120, although this depends on whether the repository accepts waste from reactors built after Olkiluoto 3 and the operational lifetime of those reactors. The estimated total cost of final disposal of used fuel from five reactors is approximately €3 billion.

Construction of new disposal tunnels will continue progressively in parallel with operation. Posiva proposed that the final size of the repository should be increased from the planned capacity of 6500 tons of used fuel to 12,000 tons – large enough to accommodate waste from Olkiluoto 4 and the proposed Loviisa 3 – and STUK supported this figure. In July 2010, Parliament voted in favor of an expansion to 9000 tons to accommodate the used fuel from Olkiluoto 4. Posiva claims that it will have no space in the planned repository for fuel from Fennovoima.

Disposal will be based on the multi-barrier KBS-3 system, developed by the Swedish Nuclear Fuel and Waste Management Company (SKB). Encapsulation will involve putting 12 fuel assemblies into a boron steel canister and enclosing this in a copper capsule. Each capsule will be placed in its own hole in the repository and backfilled with bentonite clay. The used fuel will be retrievable at every stage of the disposal process.

3.10 France

- France derives over 75% of its electricity from nuclear energy. This is due to a longstanding policy based on energy security.
- France is the world's largest net exporter of electricity due to its very low cost of generation, and gains over € 3 billion per year from this.
- France has been very active in developing nuclear technology. Reactors and fuel products and services are a major export.
- It is building its first Generation III reactor and planning a second.
- About 17% of France's electricity is from recycled nuclear fuel.

3.10.1 Fuel cycle - back end

France chose the closed fuel cycle at the very beginning of its nuclear program, involving reprocessing used fuel so as to recover uranium and plutonium for re-use and to reduce the volume of high-level wastes for disposal. Recycling allows 30% more energy to be extracted from the original uranium and leads to a great reduction in the amount of wastes. Overall the closed fuel cycle cost is assessed as comparable with that for direct disposal of used fuel and preserves a resource which may become more valuable in the future. Back end services are carried out by Areva NC. Used fuel storage in pools at reactor sites is relatively brief, and no dry storage is used.

Used fuel from the French reactors and from other countries is sent to Areva NC's La Hague plant in Normandy for reprocessing. This has the capacity to reprocess up to 1700 tons per year of used fuel in the UP2 and UP3 facilities. The treatment extracts 99.9% of the plutonium and uranium for recycling, leaving 3% of the used fuel material as high-level wastes which are vitrified and stored there for later disposal. Typical input today is 3.7% enriched used fuel from PWR and BWR reactors with burn-up to 45 GWd/t, after cooling for four years. In 2009 Areva reprocessed 929 tons, most from EdF but 79 t from SOGIN in Italy. By 2015 it aims for a throughput of 1500 t/yr.

EdF has been sending some 850 tons for reprocessing out of about 1200 tons of used fuel discharged per year, though from 2010 it will send 1050 t. The rest is preserved for later reprocessing to provide the plutonium required for the start-up of Generation IV reactors. Reprocessing is undertaken a few years after discharge, following some cooling. Some 8.5 tons of plutonium and 810 tons of reprocessed uranium (RepU) are recovered each year from the 850 tons treated each year to 2009. The plutonium is immediately shipped to the 195 t/yr Melox plant near Marcoule for prompt fabrication into about 100 tons of MOX fuel, which is used in 20 of EdF's 900 MWe reactors. Four more are being licensed to use MOX fuel.

Used MOX fuel and used RepU fuel is stored pending reprocessing and use of the plutonium in Generation IV fast reactors. These discharges have amounted to about 140 tons per year, but rise to 200 tons from 2010. Used MOX fuel is not reprocessed at present.

EdF's recycled uranium (RepU) is converted in Comurhex plants at Pierrelatte, either to U_3O_8 for interim storage or to UF_6 for re-enrichment in centrifuge facilities there or at Seversk in Russia. RepU conversion and enrichment require dedicated facilities due to its specific isotopic composition (presence of even isotopes - notably U-232 and U-236 - the former gives rise to gamma radiation, the latter means higher enrichment is required). It is the reason why the cost of these operations may be higher than for natural uranium. However, taking into account the credit from recycled materials (natural uranium savings), commercial grade RepU fuel is competitive and its cost is more predictable than that of fresh uranium fuel, due to uncertainty about future uranium concentrate prices.

About 500 tU per year of French RepU as UF6 is sent to JSC Siberian Chemical Combine at Seversk for re-enrichment. The enriched RepU UF6 from Seversk is then turned into UO2 fuel in Areva NP's FBFC Romans plant (capacity 150 t/yr). EdF has used it in the Cruas 900 MWe power reactors since the mid 1980s. The main RepU inventory constitutes a strategic resource, and EdF intends to increase its utilization significantly. The enrichment tails remain at Seversk, as the property of the enricher.

Considering both plutonium and uranium, EdF estimates that about 20% of its electricity is produced from recycled materials. Areva's estimate is 17% from both MOX and RepU.

Areva has the capacity to produce and market 150 t/year of MOX fuel at its Melox plant for French and foreign customers (though it is licensed for 195 t/yr). In Europe 35 reactors have been loaded with MOX fuel. Contracts for MOX fuel supply were signed in 2006 with Japanese utilities. All these fuel cycle facilities comprise a significant export industry and have been France’s major export to Japan. At the end of 2008 Areva was reported to have about 30 t/yr in export contracts for MOX fuel, with demand very strong. However, EdF has priority.

To the end of 2009 about 27,000 tons of LWR fuel from France and other countries had been reprocessed at La Hague. In addition, about 5000 tons of gas-cooled reactor natural uranium fuel was earlier reprocessed there and over 18,000 tons at the UP1 plant for such fuel at Marcoule, which closed in 1997.

At the end of 2008 Areva and EdF announced a renewed agreement to reprocess and recycle EdF's used fuel to 2040, thereby securing the future of both La Hague and Melox plants. The agreement supports Areva's aim to have La Hague reprocessing operating at 1500 t/yr by 2015, instead of two thirds of that in 2008. It also means that EdF increases the amount of its used fuel sent for reprocessing to 1050 t/yr from 2010, and Melox produces 120 t/yr MOX fuel for EdF then, up from 100 tons in 2009. It also means that EdF will recycle used MOX fuel.

Under current legislation, EdF is required to have made provision for its decommissioning and final waste management liabilities by 2011, but under a new bill that deadline would be deferred until 2016. At the end of 2009, EdF was reported to have

€ 11.4 billion in its dedicated back-end fund, compared with an estimated liability of € 16.9 billion.

France's back-end strategy and industrial developments are to evolve progressively in line with future needs and technological developments. The existing plants at La Hague (commissioned around 1990) have been designed to operate for at least forty years, so with operational and technical improvements taking place on a continuous basis they are expected to be operating until around 2040. This will be when Generation IV plants (reactors and advanced treatment facilities) should come on line. In this respect, three main R&D areas for the next decade include:

* The COEX process based on co-extraction and co-precipitation of uranium and plutonium together as well as a pure uranium stream (eliminating any separation of plutonium on its own). This is designed for Generation III recycling plants and is close to near-term industrial deployment.
* Selective separation of long-lived radionuclides (with a focus on Am and Cm separation) from short-lived fission products based on the optimization of DIAMEX-SANEX processes for their recycling in Generation IV fast neutron reactors with uranium as blanket fuel. This option can also be implemented with a combination of COEX and DIAMEX-SANEX processes.
* Group extraction of actinides (GANEX process) as a long term R&D goal for a homogeneous recycling of actinides (i.e. U-Pu plus minor actinides together) in Generation IV fast neutron reactors as driver fuel.

All three processes are to be assessed as they develop, and one or more will be selected for industrial-scale development with the construction of pilot plants. In the longer term the goal is to have integral recycling of uranium, plutonium and minor actinides. In practical terms, a technology - hopefully GANEX or similar - will need to be validated for industrial deployment of Gen IV fast reactors about 2040, at which stage the present La Hague plant will be due for replacement.

3.10.2 Radioactive waste management

Waste disposal is being pursued under France's 1991 Waste Management Act (updated 2006) which established ANDRA as the national radioactive waste management agency and which set the direction of research - mainly undertaken at the Bure underground rock laboratory in eastern France, situated in clays. Another laboratory is researching granites. Research is also being undertaken on partitioning and transmutation, and long-term surface storage of wastes following conditioning. Wastes disposed of are to be retrievable.

ANDRA reported to the government so that parliament could decide on the precise course of action. After strong support in the National Assembly and Senate, the Nuclear Materials and Waste Management Program Act was passed in June 2006 to apply for 15 years. This formally declares deep geological disposal as the reference solution for high-level and long-lived radioactive wastes and sets 2015 as the target date for licensing a repository and 2025 for opening it. It also affirms the principle of reprocessing used fuel and using recycled plutonium and uranium "in order to reduce the quantity and toxicity" of final wastes and calls for construction of a prototype fourth-generation reactor by 2020 to test transmutation of long-lived actinides. The cost of the repository (in 2002 €) is expected to be around € 15 billion: 40% construction, 40% operation for 100 years, and 20% ancillary (taxes and insurance). However, with design changes and cost escalation, this is reported to have doubled. Funds for waste management and decommissioning remain segregated but with the producers rather than in an external fund.

The Act defines three main principles concerning radioactive waste and substances: reduction of the quantity and toxicity, interim storage of radioactive substances and ultimate waste, and deep geological disposal. A central point is the creation of a national management plan defining the solutions, the goals to be achieved and the research actions to be launched to reach these goals. This plan is updated every three year and published according to the law on nuclear transparency and security.

The Act is largely in line with recommendations to the government from the Commission Nationale d'Evaluation (CNE) or National Scientific Assessment Committee following 15 years of research. Their report identified the clay formation at Bure as the best site but was skeptical of partitioning and transmutation for high-level wastes. It said that used MOX fuel should be stored indefinitely as a plutonium resource for future fast neutron reactors rather than being recycled now or treated as waste. In a 2010 report CNE said that transmutation of minor actinides in fast reactors would add about 10% to power cost, and transmutation of all actinides in an accelerator-driven system (ADS) would add about 20%. Wastes from transmutation reactors will be kept in interim storage for at least 70 years.

Earlier, an international review team reported very positively on the plan by ANDRA for a deep geological repository complex in clay at Bure. In 1999 ANDRA was authorized to build an underground research laboratory at Bure to prepare for disposal of vitrified high-level wastes (HLW) and long-lived intermediate-level wastes.

ANDRA is designing its Bure repository - the Industrial Centre for Geological Disposal (CIGEO) - to operate at up to 90°C, which it expects to be reached about 20 years after emplacement. ANDRA expects to apply for a construction and operating license for CIGEO at the end of 2014, preceded bay public debate. Two further repositories are envisaged by ANDRA and CEA

ANDRA operates the Soulaines disposal facility for low-level (LLW) and short-lived intermediate-level wastes, and the Morvilliers facility (CSTFA) licensed to hold 650,000 cubic meters of very low-level wastes, mostly from plant dismantling, in the Aube district around Troyes east of Paris.

In June 2008, ANDRA officially invited 3,115 communities with favorable geology to consider hosting a facility for disposal of long-lived LLW (FAVL, containing radionuclides with half lives over 30 years). This is 70,000 m^3 (18,000 tons) of graphite from early gas-cooled reactors and 47,000 m^3 of radium-bearing materials from the manufacture of catalytic converters and electronic components, as well as wastes from mineral and metal processing that cannot be placed in Andra's low-level waste disposal center in Soulaines. In response, 40 communities put themselves forward for consideration. Preliminary studies completed late in 2008 by ANDRA revealed that two – Auxon and Pars-lès-Chavanges in the Aube district – had suitable rock formations and environments for the disposal of the wastes, but after intense lobbying by anti-nuclear groups both withdrew. Investigations will proceed into 2010. A repository is likely to be in clay, about 15 meters below the land surface.

In April 2007 the government appointed 12 new members to the CNE to report on progress in France's waste management R&D across EdF, CEA, ANDRA and the National Centre for Scientific Research.

EdF sets aside € 0.14 cents/kWh of nuclear electricity for waste management costs, and said that the 2004 Areva contract was economically justified even in the new competitive environment of EU electricity supply. Total provisions at the end of 2004 amounted to €13.4 billion, €9.6 billion for reprocessing (including decommissioning of facilities) and €3.8 billion for disposal of high-level and long-lived wastes.

In August 2010 ANDRA announced that it expected €100 million for two waste projects:

- To establish a commercially viable system to recycle materials recovered during decommissioning of nuclear facilities. The materials – mainly steel and concrete – would be used exclusively in the nuclear industry. (French law prohibits using recycled materials from nuclear installations in non-nuclear applications, which discourages recycling of decommissioning waste and threatens to quickly fill Andra’s Morvilliers disposal facility – CSTFA).

- To develop techniques to condition chemically-active intermediate-level radwastes for final disposal. Those "mixed" wastes can be in liquid, gaseous, or organic form. The goal is to condition them in the most inert physical and chemical forms possible to meet safety requirements of a deep repository. Most mixed wastes are from outside the nuclear power industry, but industry generation of them is expected to increase. Industrial-scale solutions are likely to be costly, and ANDRA is therefore seeking international partners.

3.10.3 Decommissioning

Thirteen experimental and power reactors are being decommissioned in France, nine of them first-generation gas-cooled, graphite-moderated types, six being very similar to the UK Magnox type. There are well-developed plans for dismantling these (which have been shut down since 1990 or before). However, progress awaits the availability of sites for disposing of the intermediate-level wastes and the alpha-contaminated graphite from the early gas-cooled reactors. At least one of these, Marcoule G2, has been fully dismantled.

The other four include the 1200 MWe Super Phenix fast reactor, the veteran 233 MWe Phenix fast reactor, the 1966 prototype 305 MWe PWR at Chooz, and an experimental 70 MWe GCHWR at Brennilis. A license was issued for dismantling Brennilis in 2006, and for Chooz A in 2007.

Table 9 - Decommissioned Power Reactors in France

Reactor	Type	MWe	Operational
Chooz A	PWR	300	1967-91
Brennilis	GCHWR	70	1967-85
Marcoule G1	GCR	2	1956-68
Marcoule G2	GCR	40	1959-80
Marcoule G3	GCR	40	1960-84
Chinon A1	GCR	70	1963-73
Chinon A2	GCR	200	1965-85
Chinon A3	GCR	480	1966-90
Saint-Laurent A1	GCR	480	1969-90
Saint-Laurent A2	GCR	515	1971-92
Bugey 1	GCR	540	1972-94
Creys-Malville	FNR	1240	1986-97
Phenix	FNR	233	1973-2009

Materials arising from EdF's decommissioning include: 500 tons of long-lived intermediate-level wastes, 18,000 tons of graphite, 41,000 tones of short-lived intermediate-level wastes and 105,000 tons of very low level wastes.

The Eurodif gaseous diffusion enrichment plant at Tricastin is expected to generate 110,000 tons of steel and 20,000 tons of aluminum that could be recycled for use in ANDRA’s disposal centers or elsewhere in the industry.

Organization and financing of final decommissioning of the UP1 reprocessing plant at Marcoule was settled in 2004, with the Atomic Energy Commission (CEA) taking it over. The total cost is expected to be some € 5.6 billion. The plant was closed in 1997 after 39 years of operation, primarily for military purposes but also taking the spent fuel from EdF's early gas-cooled power reactors. It was operated under a partnership - Codem, with 45% share by each of CEA and EdF and 10% share by Cogema (now Areva NC). EdF and Areva will now pay CEA € 1.5 billion and be clear of further liability.

EdF puts aside € 0.14 cents/kWh for decommissioning and at the end of 2004 it carried provisions of € 9.9 billion for this. By 2010 it will have fully funded the eventual decommissioning of its nuclear power plants (from 2035). Early in 2006 it held € 25 billion segregated for this purpose, and is on track for € 35 billion in 2010. Areva has dedicated assets already provided at the level of its future liabilities.

In April 2008 ASN issued a draft policy on decommissioning which proposes that French nuclear installation licensees adopt "immediate dismantling strategies" rather than safe storage followed by much later dismantling. The policy foresees broad public information in connection with the decommissioning process.

3.11 Germany

- Germany until March 2011 obtained one quarter of its electricity from nuclear energy, using 17 reactors.
- A coalition government formed after the 1998 federal elections had the phasing out of nuclear energy as a feature of its policy. With a new government in 2009, the phase-out was cancelled, but then reintroduced in 2011.
- Public opinion in Germany remains ambivalent and at present does not support building new nuclear plants.

3.11.1 Radioactive waste management

In 1963 the federal government issued a recommendation to use rock salt formations for radioactive waste disposal. In 1973 planning for a national repository started, and in 1976 the Atomic Energy Act was amended to make such disposal a responsibility of the federal government.

The utilities are responsible for interim storage of spent fuel and have formed joint companies to build and operate off-site surface facilities at Ahaus and Gorleben. However, current policy is for interim storage at reactor sites.

The federal government through the Federal Office for Radiation Protection (BfS) is responsible for building and operating final repositories for high-level waste, but progress in this has been hindered by opposition from Länder governments. DBE is the company actually building and operating the repository projects - Konrad and Gorleben, while decommissioning Morsleben.

Following an exhaustive site selection process the state government of Lower Saxony in 1977 declared the salt dome at Gorleben to be the location for a national center for disposal of radioactive wastes. It is now considered a possible site for geological disposal of high-level wastes. These will be about 5% of total wastes with 99% of the radioactivity. A pilot conditioning plant is located at Gorleben. The site could be available as a final repository from 2025, with a decision to be made about 2019. Some € 1.5 billion was spent over 1979 to 2000 researching the site. Work then stopped due to political edict, but the new government in 2009 approved resumption of excavation.

Other proposals are for a HLW repository in opalinus clay, which occurs in a number of places in Germany. In July 2009 new repository criteria came into force, replacing rules dating from 1983. Authorities may now license a high-level waste (HLW) repository only on the basis of scientific demonstration that the waste will be stable in the repository for a million years. In addition, all HLW disposed of in any German repository must be retrievable during the entire period the repository is operated.

Separated high-level wastes from past reprocessing in France are expected to be returned to Germany by 2022 and stored. A total of 166 large casks of glass canisters will be involved, 39 of these are already in storage at Gorleben. A further 300+ casks with canisters of compacted wastes from reprocessing could immediately go to a final repository, the canisters possibly in to boreholes.

A pilot reprocessing plant known as WAK (Wiederaufarbeitungsanlage Karlsruhe Betriebsgesellschaft) operated at Karlsruhe from 1971 to 1991, processing 206 tons of used fuel. The separated HLW from this is stored there in liquid form, and after a series of political delays, is to be vitrified in 2009-12. The vitrified waste is to be stored at Greifswald while awaiting disposal in a geological repository. The low- and intermediate-level wastes from WAK were disposed of in the salt mine repository at Asse in Lower Saxony, and comprised about half of the wastes emplaced there.

The Asse salt mine repository, licensed by federal and state agencies in the 1960s and 1970s, is now closed. It received wastes from 1967 to 1978, and it is currently in poor condition and is seen to represent a failure of proper licensing process. The BfS decided in 2010 that the wastes should be moved from it, and rejected an alternative of filling it with concrete to provide a stable matrix for the 126,000 drums there. The wastes are likely to be moved to Konrad.

The Konrad site (a former iron ore mine) has been under development as a repository since 1975 and was licensed in 2002 for intermediate- and low-level waste disposal, but legal challenges were mounted. These were dismissed in March 2006 and again in April 2007. A construction license was issued in January 2008. Konrad will initially take some 300,000 cubic meters of wastes - 95% of the country's waste volume, with 1% of the radioactivity. DBE plans for it eventually to accommodate 650,000 cubic meters of wastes. It is expected to be operational about 2014.

The Ahaus facility is used for storing intermediate-level wastes, including some used HEU fuel from research reactors. In 2010 the BfS approved shipment of 951 used fuel elements from the Rossendorf reactor in 18 sealed containers to Mayak in Russia for reprocessing, on the basis of the Russian Research Reactor Fuel Return Program. Rossendorf, in East Germany, was closed in 1991.

The salt dome repository at Morsleben in East Germany for low and intermediate-level wastes was licensed in 1981, re-licensed post reunification, and was closed in 1998. It is in poor condition and is being stabilized with concrete at a cost reported to be € 2.2 billion.

Konrad, Asse and Morsleben are all in central Germany between Hanover and Magdeburg. Gorleben is about 100 km southeast of Hamburg. Ahaus is in western Germany.

3.11.2 Decommissioning

Nineteen experimental and commercial reactors have been shut down and are being decommissioned. Five of these are VVER-440 units at Greifswald, closed in 1990 following reunification (unit 6 was complete but did not operate), with 235 unused fuel assemblies being sold to Paks in 1996. Unit 5 had a partial core melt in November 1989 due to malfunctioning valves (root cause: shoddy manufacture) and was never restarted.

Five are various BWRs, two are HTRs, one is the large and relatively modern Muelheim-Kaerlich PWR shut down since 1988 due to licensing difficulties, one is Stade PWR closed in November 2003, one is Obrigheim PWR closed in May 2005, one is a prototype GCHWR and one is a prototype VVER. Gundremmingen A was shut down following an accident in 1977. High tension lines from the plant short circuited requiring rapid shutdown of the plant, which resulted in pressure relief valves flooding it with slightly radioactive water. Repairs and modernization were deemed uneconomic

Eleven of the 19 involve full demolition and site clearance. These will create about 10,000 cubic meters of decommissioning waste.

Two units of a 4-unit VVER-1000/V320 power station were under construction at Stendal but halted in 1990. Unit 1 was about 85% complete.

Decommissioning the currently operating reactors is expected to produce some 115,000 cubic meters of decommissioning wastes.

Table 10 - Decommissioned power and experimental reactors in Germany

Reactor	Type	MWe net each	Years operating each	Shut down
Greifswald 1-4	VVER-440/V230	408	Up to 16	1990
Greifswald 5	VVER-440/V213	408	0.5	11/1989
Gundremmingen A	BWR	237	10	1/1977
Grosswelzheim	Prototype BWR	25	1	1971
Kahl	Experimental BWR	15	24	1985
Kalkar KNK 2	Prototype FNR	17	13	1991
Lingen	Prototype BWR	183	10	1979
Muelheim-Kaerlich	PWR	1219	2	1988
MZFR	Experimental PHWR	52	18	1984
Neideraichbach	Experimental GCHWR	100	1	1974
Obrigheim	PWR	340	36	2005
Rheinsberg	VVER-70/V210	62	24	1990
Stade	PWR	640	31	2003
Wuergassen	BWR	640	22	1994
Juelich AVR	Experimental HTR	13	21	1989
THTR	Prototype HTR	296	3	1988

3.12 Hungary

- Hungary has four nuclear reactors generating more than one-third of its electricity.
- Its first commercial nuclear power reactor began operating in 1982.
- The Hungarian Parliament has expressed overwhelming support for building two new power reactors.

3.12.1 Fuel cycle

Hungary has some uranium resources around the Mecsek deposit in the south of the country, but no present production. The Mecsek underground mine near Pécs operated from 1958 to 1997. Initially ore was shipped to Estonia for milling, but from 1963 it was milled on site and the concentrate was exported to the Soviet Union. A total of about 21,000 tU was produced at an average recovery of 50-60%. Since 1997, the mine has been decommissioned and remediated at considerable expense (about €110 million).

In August 2008, the Australian company Wildhorse Energy Ltd joined with state-owned Mecsekérc to assess the feasibility of restarting uranium mining at Mecsek Hills. This led to an agreement with Mecsekérc and Mecsek Öko signed in October 2009 which covered all of the uranium resources in the Mecsek region over some 72 sq kmb. A decision on proceeding with a pre-feasibility study on mining is expected in 2010 once a technical review is completed. Wildhorse has an 11,600 tU JORC-compliant inferred resource, plus the adjacent Mecsek underground mine lease and four exploration areas in the vicinity. All fuel supply is contracted from Tvel in Russia.

3.12.2 2003 Fuel damage incident

A program to chemically clean partially used fuel was curtailed following an accident, which was rated Level 3 on the International Nuclear Event Scale (INES). In 2001, unit 2 at Paks was the first ever reactor to be reloaded with fuel that had been chemically cleaned; however, in April 2003, at the same unit, 30 fuel assemblies were badly damaged inside a cleaning tank due to insufficient cooling. The assemblies overheated in the cleaning tank submerged in the transfer pond so that most became deformed with burst cladding, releasing a lot of radioactivity into the water, with noble gases into the plant area. Five batches of fuel had been cleaned before the incident, to remove magnetite corrosion products from the steam generators, which impeded coolant flow in the core. Radioactive gases were emitted through the stack for several days, and the reactors were out of service for 18 months.

3.12.3 Radioactive waste management

Although preparations are being made for direct disposal of used fuel without reprocessing, there is no policy decision on reprocessing and it appears unlikely that used nuclear fuel will be reprocessed. In the past, some used fuel has been returned to Russia for reprocessing, but without repatriation of separated fissile materials.

Since 1998, a levy on nuclear power production is paid into the Central Nuclear Financial Fund to pay for storage and disposal of radioactive wastes, including used fuel, and decommissioning.

The state-owned body responsible for all waste management, waste disposal and decommissioning is the Public Limited Company for Radioactive Waste Management (Radioaktív Hulladékokat Kezelő Kft., RHK Kft), formerly the Public Agency for Radioactive Waste Management (PURAM).

Under 1995 policy, used fuel is stored in pools at Paks for five years then transferred to an interim (50-year) dry storage facility there. For low- and intermediate-level wastes, the Püspökszilágy Radioactive Waste Treatment and Disposal Facility (RWTDF) began operation in 1977. The RWTDF also accepted wastes from Paks until 1996 and the 5040 m3 capacity facility became full in 2005.

Following the decision to construct a new repository for low- and intermediate-level wastes from Paks, PURAM carried out geological investigations over a decade, and finally focused on a repository site in the south of the country, about 30 km from Pécs. In mid-2005, the residents of Bátaapáti voted to approve construction of a repository for low- and intermediate-level wastes there, and this was approved by Parliament. In December 2006, the government declared the Bátaapáti site an "investment of extraordinary significance", paving the way for accelerated licensing. The €150 million surface facilities of the National Radioactive Waste Repository were licensing. The €150 million surface facilities of the National Radioactive Waste Repository were opened in October 2008, and construction of underground vaults for intermediate-level wastes is expected to be completed in 2011, allowing operation from 2012.

Paks waste that was sent to RWTDF at Püspökszilágy will eventually be moved to Bátaapáti National Radioactive Waste Repository for final disposal, so that waste disposed at RWTDF will only derive from institutional (i.e. non-power) sources.
For high-level wastes, a claystone formation near Buda in the southwest Mecsek Mountains is being investigated, and a preliminary safety analysis has been made for a deep geological repository there. It is expected to begin operation after 2060.

3.13 India

- Nuclear power supplied 15.8 billion kWh (2.5%) of India's electricity in 2007.
- India has a flourishing and largely indigenous nuclear power program and expects to have a nuclear capacity of 20,000 MWe on line by 2020 and 63,000 MWe by 2032. It aims to supply 25% of electricity from nuclear power by 2050.
- Because India is outside the Nuclear Non-Proliferation Treaty due to its weapons program, it was for 34 years largely excluded from trade in nuclear plant or materials, which has hampered its development of civil nuclear energy until 2009.
- Due to these trade bans and lack of indigenous uranium, India has uniquely been developing a nuclear fuel cycle to exploit its reserves of thorium.
- India has a vision of becoming a world leader in nuclear technology due to its expertise in fast reactors and thorium fuel cycles.

The Atomic Energy Establishment was set up at Trombay, near Mumbai, in 1957 and renamed as Bhabha Atomic Research Centre (BARC) ten years later.

3.13.1 Radioactive waste management

Radioactive wastes from the nuclear reactors and reprocessing plants are treated and stored at each site. Waste immobilization plants are in operation at Tarapur and Trombay and another is being constructed at Kalpakkam. Research on final disposal of high-level and long-lived wastes in a geological repository is in progress at BARC.

Processes for treating reactor-produced wastes have been established and plants meeting regulatory requirements have been in operation during the past several decades. This is also the case with waste generated from fuel reprocessing plants. The first waste immobilization plant at Tarapur is in service and a Solid Storage Surveillance Facility (S3F) has also been set up for interim storage of waste. A Waste Immobilization Plant (WIP) has been installed at Trombay and another WIP is under construction at Kalpakkam. R&D work for ultimate disposal of high level and alpha bearing wastes in a repository is in progress.

3.14 Iran

- A large nuclear power plant has started up in Iran, after many years construction.
- The country also has a major program developing uranium enrichment, and this was concealed for many years.
- Iran has not suspended its enrichment-related activities or its work on heavy water related projects, as required by the UN Security Council.

Waste management services are under the responsibility of the Atomic Energy Organization of Iran (AEOI).

3.15 Japan

~~~~~~~~

Note that this report is a snapshot of nuclear power infrastructure and international waste management programs that is current as of August 2011, with one notable exception. No attempt has been made to discuss the currently evolving world-wide response to the tragic consequences of the earthquake and tsunami that devastated Japan on March 11, 2011, leaving more than 15,000 people dead and more than 8,000 people missing, and severely damaging the Fukushima Daiichi nuclear power complex.

~~~~~~~~

- Japan needs to import some 80% of its energy requirements.
- Its first commercial nuclear power reactor began operating in mid 1966, and nuclear energy has been a national strategic priority since 1973.
- The country's 50 main reactors provide some 30% of the country's electricity and this is expected to increase to at least 40% by 2017.
- Japan has a full fuel cycle set-up, including enrichment and reprocessing of used fuel for recycle.

3.15.1 Fuel cycle - back end

For energy security reasons, and notwithstanding the low price of uranium for many years, Japanese policy since 1956 has been to maximize the utilization of imported uranium, extracting an extra 25-30% of energy from nuclear fuel by recycling the unburned uranium and plutonium as MOX.

At Tokai, JNC (now JAEA) has operated a 90 t/yr pilot reprocessing plant using PUREX technology which has treated 1116 tons of used fuel between 1977 and its final batch early in 2006. It processed over 1000 tons of used fuel, with a Pu-U mixed product. The plant will now focus on R&D, including reprocessing of MOX fuel. JAEA operates spent fuel storage facilities there and is proposing a further one. It has also operated a pilot high-level waste (HLW) vitrification plant at Tokai since 1995. Tokai is the main site of JAEA's R&D on HLW treatment and disposal.

Until a full-scale plant was ready in Japan, the reprocessing of used fuel has been largely undertaken in Europe by BNFL and AREVA (4200t and 2900t respectively), with vitrified high-level wastes being returned to Japan for disposal. Areva's reprocessing finished in 2005, and commercial operation of JNFL's reprocessing plant at Rokkasho-mura was scheduled to start in 2008. Used fuel has been accumulating there since 1999 in anticipation of its full-scale operation (shipments to Europe finished in 1998).

Reprocessing involves the conventional Purex process, but Toshiba is developing a hybrid technology using this as stage 1 to separate most uranium, followed by an electrometallurgical process to give two streams: actinides (plutonium and minor actinides) as fast reactor fuel, and fission products for disposal.

3.15.2 Rokkasho complex - reprocessing and wastes

In 1984, the Federation of Electric Power Companies (FEPC) applied to the Rokkasho-mura village and Aomori prefecture for permission to construct a major complex including uranium enrichment plant, low-level waste (LLW) storage center, HLW (used fuel) storage center, and a reprocessing plant. Currently JNFL operates both LLW and HLW storage facilities there while its 800 t/yr reprocessing plant is under construction and is being commissioned. The used fuel storage capacity is 20,400 tons.

In October 2004 the Atomic Energy Commission advisory group decided by a large majority (30 to 2) to proceed with the final commissioning and commercial operation of JNFL's 800 t/yr Rokkasho-mura reprocessing plant, costing some JPY 2.4 trillion (US$ 20 billion). The Commission rejected the alternative of moving to direct disposal of spent fuel, as in the USA. This was seen as a major confirmation of the joint industry-government formulation of nuclear policy for the next several decades.

A 2004 government study projected that over the next 60 years it would be significantly more expensive to reprocess - at 1.6 yen/kWh, compared with 0.9 - 1.1 yen for direct disposal. This translates to 5.2 yen/kWh overall generating cost compared with 4.5 - 4.7 yen, without considering the implications of sunk investment in the new plant, or apparently the increased price of uranium since 2004.

The Rokkasho-mura reprocessing plant was due to start commercial operation in November 2008, following a 28 month test phase plus some delay at the end of 13 years construction. The intended date is now October 2012, the ongoing delay being due to problems in the locally-designed vitrification plant for HLW at the end of the line (see below). The main plant is based on Areva's La Hague technology, and in late 2007 the twenty-year cooperation agreement with Areva was extended and related specifically to Global Nuclear Energy partnership (GNEP) goals. The modified PUREX process now employed leaves some uranium with the plutonium product - it is a 50:50 mix, so there is no separated plutonium at any time, alleviating concerns about potential misuse.

In FY 2007 (to end March 2008) some 210 tons of used fuel was reprocessed. In FY 2008 it was expected to reprocess 395 tons of used fuel, from which it will recover 1.9 tons of fissile plutonium (in reactor-grade material). In FY 2009 about 160 tons of fresh used fuel is expected to be reprocessed, yielding 0.9 t fissile plutonium (Puf), and apparently 425 tons of stored fuel, to recover an additional 2.3 t Puf.

Active testing at the new vitrification plant attached to the Rokkasho reprocessing plant commenced in November 2007, with separated high-level wastes being combined with borosilicate glass. The plant takes wastes after uranium and plutonium are recovered from used fuel for recycle, leaving 3% of the used fuel as high-level radioactive waste. However, the furnaces (developed at Tokai, rather than being part of the French technology) have proved unable to cope with impurities in the wastes, and commissioning is much delayed. Finally in 2010 JNFL decided to redesign the unit to better control the temperature of the molten glass, resulting in a delay to October 2012 for commissioning.

The new Rokkasho plant will treat 14,000 tons of used fuel stockpiled there to end of 2005 plus 18,000 tons of used fuel arising from 2006, over some 40 years. It will produce about 4 tons of fissile plutonium per year, enough for about 80 tons of MOX fuel.

3.15.3 Mutsu storage

In 2010 Recyclable-Fuel Storage Co obtained approval to construct a facility at Mutsu in Aomori prefecture to store used fuel from Tepco and Japco nuclear plants for some 50 years before reprocessing at the Japan Nuclear Fuel plant. It is expected to take 3000 t/yr. Construction started in July 2010 and is due to be completed by 2012.

3.15.4 High-level wastes

In 1995, Japan's first high-level waste (HLW) interim storage facility opened in Rokkasho-mura - the Vitrified Waste Storage Centre. The first shipment of vitrified HLW from Europe (from the reprocessing of Japanese fuel) also arrived in that year. The last of twelve shipments from France was in 2007, making a total of 1310 canisters. Shipments from UK started in 2010, with 1850 canisters to go in about 11 shipments. These include an equivalent amount of HLW to avoid the need to transport greater amounts of low-level wastes (LLW). The first shipment arrived in March 2010.

In 2005 Tepco and JAPC announced that a Recyclable Fuel Storage Centre would be established in Mutsu, operating from mid 2012 with 5000 t capacity. The JPY 100 billion facility will provide interim storage for up to 50 years before used fuel is reprocessed. NISA approved this in August 2010.

In May 2000, the Japanese parliament (the Diet) passed the Law on Final Disposal of Specified Radioactive Waste (the "Final Disposal Law") which mandates deep geological disposal of high-level waste (defined as only vitrified waste from reprocessing spent reactor fuel). In line with this, the Nuclear Waste Management Organization (NUMO) was set up in October 2000 by the private sector to progress plans for disposal, including site selection, demonstration of technology there, licensing, construction, operation, monitored retrievable storage for 50 years and closure of the repository. Some 40,000 canisters of vitrified HLW are envisaged by 2020, needing disposal - all the arisings from the Japanese nuclear plants until then.

NUMO has begun an open solicitation process to find a site, and will shortlist those that are proffered and potentially suitable. The promising ones will be subject to detailed investigation from 2012. A third phase to 2030 will end with site selection.

Repository operation is expected from about 2035, and the JPY 3000 billion (US$ 28 billion) cost of it will be met by funds accumulated at 0.2 yen/kWh from electricity utilities (and hence their customers) and paid to NUMO. This sum excludes any financial compensation paid by the government to local communities.

In mid 2007 a supplementary waste disposal bill was passed which says that final disposal is the most important issue in steadily carrying out nuclear policy. It calls for the government to take the initiative in helping the public nationally to understand the matter by promoting safety and regional development, in order to get the final disposal site chosen with certainty and without delay. It also calls for improvement in disposal technology in cooperation with other countries, revising the safety regulations as necessary, and making efforts to recover public trust by, for example, establishing a more effective inspection system to prevent the recurrence of data falsifications and cover-ups.

The technical aspects of Japan's HLW disposal concept is based on two decades' work under JNC (now JAEA) involving generic evaluation of repository requirements in Japan's geology. The technical aspects of Japan's HLW disposal concept is based on two decades' work under JNC (now JAEA) involving generic evaluation of repository requirements in Japan's geology. Since 2000 the Horonobe Underground Research Centre has been under development on Hokkaido, investigating sedimentary rocks about 500m deep, and in November 2005 construction of the underground shafts and galleries was launched. JAEA runs the Tona Geoscience Centre at Toki, in Gifu prefecture, and is building a similar facility, the Mizunami Underground Research Laboratory there, in igneous rock about 1000m deep.

The basic repository concept involves sealing about 20 HLW canisters in a massive steel cask or overpack and surrounding this by bentonite clay. NUMO has built design options on this including those allowing inspection and retrieval over long periods. In particular the Cavern Retrievable (CARE) concept has emerged, involving two distinct stages: ventilated underground caverns with the wastes in overpacks (hence shielded) fully accessible, followed by backfilling and sealing the caverns after 300 years or so. The initial institutional control period allows radiological decay of the wastes so that thermal load is much reduced by stage 2 and hence the concept allows a much higher density of wastes than other disposal concepts.

The CARE concept can be adapted for spent fuel, the cask then being similar to shipping casks, except that a layer of shielding, which is required due to higher thermal and radiation output, could be removable before the cavern is backfilled and sealed. However, for spent fuel retrieval would be likely rather than merely possible, since it represents a significant potential fuel resource (via reprocessing), whereas vitrified HLW does not. Also, spent fuel would require ease of access due to the need for safeguards inspections. Eventual backfill could include depleted uranium if that is then considered a waste.

In 2004 METI estimated the costs of reprocessing spent fuel, recycling its fissile material and management of all wastes over 80 years from 2005. METI's Electricity Industry Committee undertook the study, focused on reprocessing and MOX fuel fabrication including the decommissioning of those facilities (but excluding decommissioning of power reactors). Total costs over 80 years amount to some JPY 19 trillion, contributing almost one yen (US 0.9 cents) per kilowatt-hour at 3% discount rate. About one third of these costs would still be incurred in a once-through fuel cycle, along with increased high-level waste disposal costs and increased uranium fuel supply costs. Japan's policy however is based on energy security rather than purely economic criteria.

Funding arrangements for HLW were changed in October 2005 under the new Back-end Law which set up the Radioactive Waste Management Funding and Research Centre (RWMC) as the independent funds management body. All reserves held by utilities were to be transferred to it and companies then refunded as required for reprocessing.

METI, with JNFL and FEPC, is seeking permission from the Aomori prefecture to build a low-level waste storage facility at Rokkasho. In particular, this will be for LLW returned from France from 2013.

3.15.5 Decommissioning

The Japan Power Demonstration Reactor (JPDR) decommissioning program, following its closure in 1976, established the necessary techniques for the decommissioning of commercial power reactors by the Japan Atomic Energy Research Institute (JAERI). Phase I of the program started in 1981 to develop a set of techniques and Phase II was actual dismantling of JPDR over 1986-92.

The original Tokai-1 power station, a British Magnox reactor which started up at the end of 1965 and closed down in March 1998, is being decommissioned over 20 years, the first ten as "safe storage" to allow radioactivity to decay. Phase 1 (to 2006) comprised preliminary work, in Phase 2 (to 2011) the steam generators and turbines are being removed, and in Phase 3 (to 2018) the reactor will be dismantled, the buildings demolished and the site left ready for re-use. All radioactive wastes will be classified as low-level (LLW), albeit in three categories, and will be buried - the 1% of level I wastes 50-100 meters deep. The total cost is expected to be JPY 93 billion - 35 billion for dismantling and JPY 58 billion for waste treatment including the graphite moderator (which escalates the cost significantly).

Fugen ATR (148 MWe, started up in 1978) closed in March 2003, and JAEA plans to decommission it and demolish to clear the site by 2029, at a total cost of about JPY 70 billion, including waste treatment and disposal. Plans for this were approved in February 2008.

Chubu's Hamaoka 1 & 2, earlier closed for safety-related upgrades, remained shut down following the 2007 earthquake, were written off, and are now being decommissioned.

In March 2011 units 1-4 of the Fukushima Daiichi plant (2719 MWe net) were seriously damaged in a major accident, and are written off to be decommissioned.

Table 11 - Decommissioned Reactors in Japan

Reactor	Type	Net capacity MWe	Utility	Commercial operation
JPDR	BWR	12	JAERI	2/65 - 3/76
Tokai 1	Magnox	137	Japco	7/66 - 3/98
Fugen	ATR	148	JNC	3/79 - 3/03
Hamaoka 1	BWR	515	Chubu	3/76 - 2/09
Hamaoka 2	BWR	806	Chubu	11/78 - 2/09
Fukushima I-1	BWR	439	Tepco	3/71 - 3/11
Fukushima I-2	BWR	760	Tepco	7/74 - 3/11
Fukushima I-3	BWR	760	Tepco	3/76 - 3/11
Fukushima I-4	BWR	760	Tepco	10/78 - 3/11

JAEA is responsible for research on reactor decommissioning.

3.16 Lithuania

- In 2004, the last year of having two reactors online, the country produced 13.9 billion kWh out of a total 19.3 billion kWh.
- Lithuania closed its last nuclear reactor, which had been generating 70% of its electricity, at the end of 2009.
- Electricity was a major export until the closure of Lithuania's nuclear plant.
- Plans for a new nuclear plant involve neighboring countries.

3.16.1 Radioactive waste management

The Radioactive Waste Management Agency (RATA) was established in 2001 by the Ministry of Economy for management and final disposal of all radioactive waste from the Ignalina plant. In 2007, it identified a site close to Ignalina for a near-surface final repository for low- and intermediate-level wastes and the government approved this. A group of companies led by France's Areva is developing the €10 million repository, to be completed in 2017. The repository contains a variety of facilities, the first of which should start operating in 2015. The waste storage area will be filled until approximately 2030 when the power plant is expected to be completely dismantled and all wastes secured.

Due to the pools at both reactors being essentially full, some used fuel is stored in dry casks on site. A new interim spent fuel storage facility is being built about one kilometer from the power plant, for operation from 2011.

Both Ignalina RBMK reactors are now being decommissioned. Unloading the used nuclear fuel from unit 2 is expected to continue until April 2012. By April 2016, it is expected that all fuel from unit 1 and unit 2 will have been unloaded from the used fuel storage pools into casks and transported to the new interim spent fuel storage facility, where it will remain for 50 years. For short-lived, low-level waste, a separate storage facility is planned to be operating by the end of 2010.

The total estimated cost of the Ignalina decommissioning project is over €2.5 billion, with the European Union (EU) having pledged €1.4 billion towards these costs. (Some €875 million had been received to the end of 2009.) EU funding for this work is largely through the Ignalina International Decommissioning Support Fund (IIDSF) administered by the European Bank for Reconstruction & Development (EBRD). About 95% of the required decommissioning funds have been provided by the international community, and the spending is being administered by a Central Project Management Agency (CPMA) and the EBRD. The other 5% comes from Lithuanian state funds through the state's own energy agency.

3.17 Mexico

- Mexico has two nuclear reactors generating almost 5% of its electricity.
- Its first commercial nuclear power reactor began operating in 1989.
- There is some government support for expanding nuclear energy to reduce reliance on natural gas.

3.17.1 Radioactive waste management

The government of Mexico, through the Ministry of Energy is responsible for the storage and disposal of nuclear fuels and radioactive waste irrespective of their origin.
The Energy Ministry is beginning to take administrative and budgetary steps to create a national company to manage its radioactive waste. It is also planning to sign the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

An engineered near-surface disposal site for low-level waste (LLW) operated at Piedrera between 1985 and 1987. In that time, 20,858 m3 of waste was stored.

A collection, treatment and storage centre for LLW has operated at Maquixco since 1972.

3.18 The Netherlands

- The Netherlands has one nuclear reactor generating about 4% of its electricity. A large new unit is now proposed.
- Its first commercial nuclear power reactor began operating in 1973.
- A previous decision to phase out nuclear power has been reversed. Public and political support is increasing for expanding nuclear energy.

<u>3.18.1 Radioactive waste management</u>

In the 1970s the Dutch government adopted a policy of reprocessing used nuclear fuel from both the Borssele and Dodewaard reactors. In 1984 it decided on a policy of long-term (100 years) interim storage of all the country's radioactive wastes; and a research strategy for their ultimate disposal.

This led to the establishment of the Central Organization for Radioactive Waste (COVRA), based at Borssele, close to the nuclear power station.

A low- and intermediate-level radioactive waste (LILW) management centre was commissioned at Borssele in 1992 which provides for storage of those materials.
In September 2003, COVRA's HABOG facility - an interim storage for high-level waste (HLW) was commissioned by Queen Beatrix. HABOG has two compartments, one for medium-level waste such as canisters containing fuel element claddings after reprocessing of their uranium contents; and one for the vitrified HLW returned after used fuel reprocessing (fission products and transuranics). It stores all the HLW from Dodewaard fuel reprocessed at Sellafield in UK, and all the waste returned from reprocessing Borssele fuel at La Hague. A system of natural convection operates in the second compartment to cool the heat-generating HLW.

Government policy is to eventually store HLW underground and to move towards that goal in a way such that each step is reversible. In 2001, the Government-sponsored Committee on Radioactive Waste Disposal (CORA) concluded that geological retrievable disposal is technically feasible in a safe manner, on several sites in the Netherlands.

In 2006, the Government proposed to make a decision about the siting for final disposal by 2016.

The 55 MWe Dodewaard reactor, shut down in 1997, is being decommissioned. In 2003 the last fissionable material was removed and parts of the plant were demolished. The main part will be sealed and monitored (in safestor) to-2045, before being demolished.

3.19 Pakistan

- In Pakistan, nuclear power makes a small contribution to total energy production and requirements, supplying only 2.34% of the country's electricity.
- Pakistan has a small nuclear power program, with 725 MWe capacity, but plans to increase this substantially.
- Because Pakistan is outside the Nuclear Non-Proliferation Treaty, due to its weapons program, it is largely excluded from trade in nuclear plant or materials, which hinders its development of civil nuclear energy.

3.19.1 Radioactive waste management

The PAEC has responsibility for radioactive waste management. A Radioactive Waste Management Fund is proposed in a new proposed policy. Waste Management Centres are proposed for Karachi and Chashma.

Used fuel is currently stored at each reactor in pools. Longer-term dry storage at each site is proposed. The question of future reprocessing remains open.

A National Repository for low- and intermediate-level wastes is due to be commissioned by 2015.

3.20 Romania

- Romania has two nuclear reactors generating almost 20 percent of its electricity.
- Romania's first commercial nuclear power reactor began operating in 1996. Its second started up in May 2007.
- Plans are well advanced for completing two more units.
- Romanian government support for nuclear energy is strong.

3.20.1 Radioactive waste management

Used fuel is stored at the reactors for up to ten years. It is then transferred to a dry storage facility for spent based on the Macstor system designed by AECL. The first module was commissioned in 2003.

Preliminary investigations are under way regarding a deep geological repository.

Near Cernavoda, a low- and intermediate-level waste repository is envisaged from 2005.

A radioactive waste treatment facility operates at Pitesti.

3.21 Russia

- Russia is moving steadily forward with plans for much expanded role of nuclear energy, nearly doubling output by 2020.
- Efficiency of nuclear generation in Russia has increased dramatically since the mid 1990s.
- Exports of nuclear goods and services are a major Russian policy and economic objective.
- Russia is a world leader in fast neutron reactor technology.

3.21.1 Waste management

The WNA profile for Russia does not discuss radioactive waste management. The IAEA web site does not have a profile on Russia, however it did point to a current related news item:

July 15, 2011 - Russian president Dmitry Medvedev has signed a federal law on radioactive waste management. The new bill establishes a legal framework for radioactive waste management in Russia and formally creates a unified state system for radioactive waste management. (WNN, 07.15.11).

An overview of used fuel management in Russia is summarized from additional sources, primarily:

- National Research Council 2003 - "*End Points for Spent Nuclear Fuel and High-Level Radioactive Waste in Russia and the United States"*
- Witherspoon and Bodvarsson 2006 - "*Geological Challenges in Radioactive Waste Isolation – Fourth Worldwide Review*"

Russia generates used nuclear fuel from several types of power reactors, and has agreements with several former Soviet republics for the take-back and management of fuel from similar reactors. The long-term intent is for a closed fuel cycle with most fuel to be reprocessed and reused. Currently, fuel from VVER-440 reactors is transported to PA "Mayak" where the RT-1 aqueous reprocessing facility operates. Interim storage pools hold fuel prior to processing. Fuel from VVER-1000 reactors is transported to MCC "Krasnoyarsk" and stored. The RT-2 reprocessing facility at MCC was designed to process this fuel but it has not been completed. Storage capacity includes both a large pool facility and dry storage modules. In the long-term the intent remains to reprocess this fuel, but direct disposal options have been considered. Russia has an extensive rail transportation capability for irradiated fuel, and fuel from the VVER PWRs is typically removed from reactors sites following 2-5 years of pool cooling. RBMK fuel was intended for reprocessing in the past for Pu production, but is currently stored at a combination of at-reactor facilities and consolidated facilities, including both pool and dry cask. Long-term disposition could include either direct disposal or eventual reprocessing.

Geologic disposal is the accepted pathway for highly radioactive wastes, and for intact used fuel if direct disposal is ever utilized in Russia. Several sites have used direct underground injection of liquid radioactive wastes for several decades. The disposal horizons are typically permeable layers (to provide capacity) bounded by impermeable layers (to provide isolation). Injection sites include: SCC “Seversk”, MCC “Krasnoyarsk” and NIIAR “Dimitrovgrad”. This process is being phased out and long-term plans call for development of one or more mined geologic repositories for solid wastes. A number of potential sites and host media have been considered, and there have been varying levels of investigations and conceptual designs. These include the Nizhnekansky granite massif near Krasnoyarsk, deep granite in the Kola region, permafrost at Novaya Zemlya, volcanic rocks near Mayak and clay near Leningrad. Plans call for repository operation in the 2030+ timeframe.

3.22 Slovakia

- Slovakia has four nuclear reactors generating half of its electricity and two more under construction.
- Slovakia's first commercial nuclear power reactor began operating in 1972.
- Government commitment to the future of nuclear energy is strong.

3.22.1 Spent fuel management

From IAEA:

By the end of 2000, the six Slovak VVER-440 units used 7 300 spent fuel assemblies. From this amount, approximately 700 assemblies were exported to the Russian Federation, 1 200 were cooled down in pools adjacent to the reactors, and 5 400 pieces were stored in a wet interim spent fuel storage facility at the Bohunice site. This facility was extensively refurbished during 1997-2000. The refurbishment resulted also in a capacity increase from 5 000 up to 14 000 fuel assemblies (or 1 680 tU). This capacity is sufficient for the fuel storage needs of both Bohunice till its expected closure and of Mochovce till 2015. By that time, it will be necessary to build a new storage facility at the Mochovce site. According to current intentions, the facility will probably be based on the dry storage technology.

The fundamental conception for the back end fuel cycle management remains unchanged. It is still expected that spent fuel will be ultimately disposed in a deep underground geological repository. Activities on the selection of an adequate site are thus continuing.

3.22.2 Radioactive waste management

From WNA:

Originally the policy was for used fuel to be disposed of without reprocessing, but in 2008 this changed to recycling it domestically.

At the beginning of 1996, the VYZ subsidiary of Slovenské Elektrárne was established for decommissioning nuclear facilities, radioactive waste and used fuel management. A separate subsidiary of Slovenské Elektrárne – Decom – was set up as a consultancy to focus on decommissioning. During Enel's 2006 acquisition of a 66% stake in SE, the SE-VYZ subsidiary, along with the Bohunice V1 reactors (which were in operation at the time), was transferred to the state as the Nuclear Decommissioning Company (Javys)o.

A treatment and conditioning plant for low- and intermediate-level wastes is operated by Javys at Bohunice, and a near-surface repository (the National Radioactive Waste Repository) at Mochovce began operation in 2001.

An interim wet storage facility for used fuel at Bohunice supplements reactor storage ponds, and has a capacity of 1680 tons (14,000 fuel assemblies). It has functioned since 1986 and is operated by Javys. Some used fuel was earlier exported to Russia for reprocessing (with Russia keeping the products).

Site selection for an underground high-level waste repository has commenced, although the country is also considering the option of participating in a shared international repository project.

Preparation for decommissioning the two Bohunice V1 reactors will begin in 2012, that work taking 13 years at an estimated cost of about €500 million. Decommissioning of the A1 reactor is underway.

A state fund for radwaste management and decommissioning was set up in 1995, with a levy of 10% of the wholesale price of electricity being paid into it by SE. It is expected to amount to €775 million by 2010. The Bohunice International Decommissioning Support Fund, administered by the European Bank of Reconstruction and Development (EBRD), was set up in 2001 to support the decommissioning of the Bohunice V1 plant, as well as to support energy projects to help minimize the impact of the early closure of the reactors.

From IAEA:

The whole amount of radioactive waste from the past operation of the Bohunice units is stored temporarily on the site. The concepts of radwaste management from nuclear power installations and other organizations using sources of ionization radiation were prepared in 1993. The following production process fixing facilities have been constructed or are being built

- A bituminization facility for fixing concentrates was commissioned in 1995;
- A vitrification facility is in the stage of active comprehensive testing;
- A radwaste-processing center consisting of a cementation facility with a possibility to densify concentrates, of a high-pressure pressing and of an incineration installation.

Low- and medium-level radwaste from Bohunice will be stored in fiber-concrete containers. To make the system of radwaste management complete, it was necessary to commission the operation of a disposal facility for low- and medium-level radwaste at the Mochovce site in 2000.

3.23 Slovenia

- Slovenia has shared a nuclear power reactor (Krsko) with Croatia since 1981.
- Nuclear power from the single reactor supplied 40% of the country's electricity in 2008.
- It has further capacity under consideration.

3.23.1 Radioactive waste management

From WNA:

Operational Low and Intermediate-level wastes are stored at Krsko, as is used fuel. The 1996 strategy for long-term management of used fuel recommends direct disposal of it, but leaves open the possibility of a later decision to reprocess it.

A permanent repository for low- and intermediate-level wastes is due to open in 2013 at Vrbina, near the Krsko plant. Site selection has been undertaken over five years, and compensation of € 5 million per year will be paid to the local community. The repository will consist of two silos holding 9400 m^3 of material, enough for Slovenia's share of Krsko arisings plus other Slovenian radwastes.

From IAEA:

The Republic of Slovenia has a small nuclear program; one operating nuclear power plant, one research reactor and one central interim storage facility for radioactive waste from small producers. In addition, there is also a uranium mine and mill in the decommissioning stage at Žirovski vrh.

The Republic of Slovenia has no operational facility for final disposal of radioactive waste or spent nuclear fuel.

The Central Interim Storage for Radioactive Waste in Brinje, situated at the IJS Reactor Infrastructure Centre, is intended for storage of low and intermediate level radioactive waste arising from medical, industrial and research applications

The waste management policy for spent nuclear fuel is to store it temporarily at the Krsko reactor site as long as it is operating. Under current plans the spent fuel would be removed into a dry storage facility (available from 2023, on unspecified location), where it would be kept for about 45 years, until disposal or export into a third country. In case of disposal, one joint deep geological repository (either in Slovenia or in Croatia) would be operating in 2068-2077, and would be closed 5 years later. The independent dry spent fuel storage facility would allow for some timing flexibility, including a few decades of waiting time before decision on spent fuel export or disposal must be made.

3.24 South Africa

- South Africa has two nuclear reactors generating 5% of its electricity.
- South Africa's first commercial nuclear power reactor began operating in 1984.
- Government commitment to the future of nuclear energy is strong, but financial constraints are severe.
- Construction of a demonstration Pebble Bed Modular Reactor has been cancelled.

The South African nuclear industry dates back to the mid-1940s, when the predecessor organization to the Atomic Energy Corporation (AEC) was formedj. In 1959, the government approved the creation of a domestic nuclear industry and planning began the next year on building a research reactor, in cooperation with the US Atoms for Peace program. The Pelindaba site near Pretoria was established in 1961, and the 20 MWt Safari-1 reactor there went critical in 1965. In 1970, the Uranium Enrichment Corporation (UCOR) was established as South Africa commenced an extensive nuclear fuel cycle program, as well as the development of a nuclear weapons capability. In 1985, UCOR was incorporated into the AEC, which became the South African Nuclear Energy Corporation (Necsa) in 1999.

3.24.1 Radioactive waste management

The 2008 National Radioactive Waste Disposal Institute Act provides for the establishment of a National Radioactive Waste Disposal Institute which will manage radioactive waste disposal in South Africa. The responsibility for nuclear waste disposal has been discharged by Necsa until now.

Necsa has been operating the national repository for low- and intermediate-level wastes at Vaalputs in the Northern Cape province. This was commissioned in 1986 for wastes from Koeberg and is financed by fees paid by Eskom. Some low- and intermediate-level waste from hospitals, industry and Necsa itself is disposed of at Necsa's Pelindaba site.

Used fuel is stored at Koeberg. In August 2008, the nuclear safety director of the Minerals and Energy department announced that Eskom would seek commercial arrangements to reprocess its used fuel overseas and utilize the resulting mixed oxide (MOX) fuel.

3.25 South Korea

- South Korea is set to become a major world nuclear energy country, exporting technology. It won a $20 billion contract to supply four nuclear reactors to UAE.
- Nuclear energy is a strategic priority for South Korea and capacity is planned to increase by 56% to 27.3 GWe by 2020, and then to 43 GWe by 2030.
- Today 21 reactors provide almost 40% of South Korea's electricity from 18.7 GWe of plant.

3.25.1 Radioactive waste management

The Korea Radioactive Waste Management Co. Ltd (KRWM) was set up early in 2009 as an umbrella organization to resolve South Korea's waste management issues and waste disposition, and particularly to forge a national consensus on high-level wastes. KHNP is the largest among the six power generating subsidiaries that separated from Korea Electric Power Corporation (KEPCO) in April 2001, accounting for approximately 25% of electricity producing facilities, hydro and nuclear combined. Until then, KHNP had been responsible for managing all its radioactive wastes. KHNP now contributes a fee of 900,000 won (US$ 705) per kilogram of used fuel to KRWM.

The Atomic Energy Act of 1988 established a 'polluter pays' principle under which KHNP was levied a fee based on power generated. A fee was also levied on Korea Nuclear Fuel Co. (KNFC). The fees were collected by MEST and paid into a national Nuclear Waste Management Fund. A revised waste program was drawn up by the Nuclear Environment Technology Institute (NETEC) and approved by the Atomic Energy Commission in 1998.

Used fuel is stored on the reactor site pending construction of a centralized interim storage facility by 2016, eventually with 20,000 ton capacity. About 10,000 t was stored at the end of 2008, onsite pool capacity being 12,000 t, about half of both figures being for Candu fuel at Wolsong. About 6000 t was stored at end of 2002. Dry storage is used for Candu fuel after 6 years cooling. Long-term, deep geological disposal is envisaged, though whether this is for used fuel as such or simply separated high-level wastes depends on national policy.

Reprocessing, either domestic or overseas, is not possible under constraints imposed by the country's cooperation agreement with the USA. However this is being appealed. KHNP has considered offshore reprocessing to be too expensive, and recent figures based on Japanese contracts with Areva in France support this view, largely due to transport costs.

Low and intermediate-level wastes (LILW) are also stored at each reactor site, the total being about 60,000 drums of 200 liters. Volume reduction (drying, compaction) is undertaken at each site. A 200 ha central disposal repository is envisaged for all this, eventually with capacity for 800,000 drums. It will involve shallow geological disposal of conditioned wastes, with vitrification being used on ILW from about 2006 to increase public acceptability.

NETEC took over the task of finding repository sites after several abortive attempts by KAERI and MEST 1988-96. In 2000 it called for local communities to volunteer to host a disposal facility. Seven did so, including Yonggwang county with 44% citizen support, but in 2001 all local governments vetoed the proposal. The Ministry of Commerce, Industry & Energy (now the Ministry of Knowledge Economy - MKE) then in 2003 selected four sites for detailed consideration and preliminary environmental review with a view to negotiating acceptance with local governments from 2004.

The area selected for the LILW facility will get 300 billion won (US$ 260 million) in community support according to "The Act for Promoting the Radioactive Waste Management Project and Financial Support for the Local Community" 2000. The aim of this is to compensate for the psychological burden on residents, to reward a community participating in an important national project, and to facilitate amicable implementation of radioactive waste management.

In November 2005, after votes in four provincial cities, Kyongju /Gyeonju on the east coast 370 km SE from Seoul was designated as the site. Almost 90% of its voters approved, compared with 67 to 84% in the other contender locations. It is close to Wolsong.

In June 2006 the government announced that the Gyeongju LILW repository would have a number of silos and caverns some 80m below the surface, initially with capacity for 100,000 drums and costing US$ 730 million. Construction started in April 2008. Further 700,000 drum capacity would be built later, total cost amounting to US$ 1.15 billion. As well as the initial US$ 260 million grant, annual fees will be paid to the local community. In December 2010 KRWM commenced operation of the facility, accepting the first 1000 drums of wastes there from the Ulchin plant. These will be held in outdoor storage until the underground repository itself is commissioned in 2012. About nine such shipments are expected annually. The site covers 2.1 sq km.

3.26 Spain

- Spain has eight nuclear reactors generating a fifth of its electricity.
- Its first commercial nuclear power reactor began operating in 1968.
- There is potential for renewed uranium mining.
- Government commitment to the future of nuclear energy in Spain has been uncertain, but is firming up.

3.26.1 Radioactive waste management

ENRESA (Empresa Nacional de Residuos Radiactivos SA) was established in 1984 as a state-owned company to take over radioactive waste management and decommissioning of nuclear plants. It is now the only state-owned part of the nuclear fuel cycle in Spain.

It drew up a General Plan for radioactive wastes which was approved by parliament in 1999. Its is based on nuclear power plant lives of 40 years, and addresses the need to manage almost 200,000 cubic meters of low and intermediate-level wastes and 10,000 cubic meters of spent fuel and other high-level wastes.

Since 1983 Spain's policy has been for an open fuel cycle, with no reprocessing. The plan for spent fuel envisages initial storage at each reactor for ten years. Some temporary storage for dry casks is also envisaged at Trillo up to 2010 and establishment of a longer-term centralized facility from then. Meanwhile research will progress on deep geological disposal as well as transmutation, with a decision on disposal to be made after 2010. Granite, clay and salt formations are under consideration.

In mid 2006 Parliament approved ENRESA's plans to develop a temporary central nuclear waste storage facility by 2010, and the CSN approved its design, which was similar to the Habog facility near the Borssele power plant in the Netherlands. In December 2009 the government called for municipalities to volunteer to host this € 700 million Almacen Temporal Centralizado facility for high-level wastes and used fuel. The government offered to pay up to € 7.8 million annually once the facility is operational. It is designed to hold for 100 years 6700 tons of used fuel and 2600 m^3 of intermediate-level wastes, plus 12 m^3 of high-level waste from reprocessing the Vandellos-1 fuel. The facility is to be built in three stages, each taking five years. Asco and Villar de Canas are two towns among eight that have volunteered, attracted by the prospect of € 700 million over 20 years and the annual direst payments, plus many jobs. A campaign of fear-mongering has been mounted by nuclear detractors to dissuade residents of the eight towns, and some regional governments are also opposed.

Waste management and decommissioning is funded by a levy of about 1% on all electricity consumed.

ENRESA has a medium and low-level radioactive waste storage facility at El Cabril, Cordoba.

3.26.2 Decommissioning

Vandellos-1, a 480 MWe gas-graphite reactor, was closed down in mid 1990 after 18 years operation, due to a turbine fire which made the plant uneconomic to repair. In 2003 ENRESA concluded phase 2 of the reactor decommissioning and dismantling project, which allows much of the site to be released. After 30 years, Safestor plans to decommission and dismantle the remainder of the plant when activity levels have diminished by 95%,.

The cost of the 63-month project was € 93 million.

In April 2006 the 142 MWe Jose Cabrera (Zorita) plant was closed after 38 years operation. Dismantling the plant will be undertaken over six years from 2010 by Enresa - total cost is estimated at € 135 million. About 4% of the plant's constituent material will need to be disposed of as radioactive waste, the rest can be recycled, including 43 tons of internal components.

3.27 Sweden

3.27.1 Nuclear fuel cycle

Sweden imports most of its nuclear fuel, including all enrichment. In the case of Forsmark, these have been provided: 20% Eurodif (diffusion), 60% Urenco, 20% Tenex (both centrifuge) – over 90% of energy input being from nuclear power.

Westinghouse has a fuel fabrication plant at Vasteras, which produces about 400 tons of BWR and PWR fuel per year.

Sweden has some uranium mineralization but no mines. Some 200 tU was produced from a black shale deposit in Ranstad in the 1960s. Another deposit is Pleutajokk, near the Arctic Circle. Canada's Mawson Resources is investigating the Hotagen District of northern Sweden and has identified several small deposits.

Australia's Aura Energy has announced JORC-compliant inferred resources of 112,000 tU at 0.014%U in the Alum black shales at Haggan near Storasen and Vasterasen in central Sweden. Molybdenum, nickel, zinc and vanadium are present and are potential co-products. The Haggan deposit is flat, with low mining costs, and though amenable to acid leach it has high carbonate levels, so bacterial heap leaching is being investigated. (Talvivaara Mining in Finland is planning to recover uranium by-product from bio-leaching similar black shale ore.)

3.27.2 Radioactive waste management

The Swedish Nuclear Fuel and Waste Management Company (Svensk Kärnbränslehantering AB, SKB) was set up by the nuclear utilities following the Waste Legislation (Stipulation Act) in 1977 to develop a comprehensive concept for the management and disposal of used fuel and other radioactive wastes. It is owned 36% by Vattenfall, 30% Forsmark, 22% OKG and 12% E.ON Sweden.

Some low-level waste is disposed of at reactor sites, some is incinerated at the Studsvik RadWaste incineration facility in Nyköping.

SKB's dedicated ship, M/S Sigyn, moves the used fuel and wastes from power plants to storage or repositories.

A final underground repository (SFR) for operational (up to intermediate-level) radioactive waste and medical and industrial radioactive wastes has been operating near Forsmark since 1988. It has 63,000 cubic meter capacity and receives about 1,000 cubic meters per year. This is also one of the locations proposed by the local Östhammar community for a final high-level waste (HLW) repository.

The CLAB interim repository for used fuel (treated as high-level waste) has been operating since 1985 at Oskarshamn, and its original 5,000 ton capacity has been expanded to 8000 tons to cater for all the fuel from all the present reactors. The used fuel is stored under water in an underground rock cavern for some 40-50 years. It will then be encapsulated in copper and stainless steel canisters for final emplacement packed with bentonite clay in a 500 meter deep repository in granite. In mid-2009 about 5,000 tons of used fuel was at CLAB.

Research at the Äspö Hard Rock Laboratory nearby has identified geological characteristics for this final deep repository. Site selection procedures from 2002 resulted in two municipalities voting to be candidate locations for a deep geological repository – Oskarshamn (Simpevarp and Laxemar) and Östhammar (Forsmark). Both these had been selected as having potentially suitable bedrock characteristics, after feasibility studies in eight municipalities. An April 2008 independent poll in both communities (N=900 in each) showed that 83% of Oskarshamn residents and 77% of those in Östhammar supported having the future repository in their own locality. Six neighboring localities were also surveyed in 2008 and, while the majority of residents were in favor of a final repository in the neighboring municipalities, support diminished as distance from ongoing nuclear power operations increased.

SKB announced its decision to locate the repository at Soderviken near Forsmark in Östhammar municipality, on the basis of it having the best geology, in June 2009. In April it had signed an investment agreement with both volunteer municipalities specifying investment of SKR 2 billion (US$ 245 million) in the two, with the majority going to the unsuccessful bidder, which will thereby be disadvantaged financially. SKB applied for a license to construct the repository in March 2011. It plans to begin site works in 2013, with full construction starting in 2015, and operation after 2020.

The repository will have 12,000 tons capacity at 500 meters depth in 1.9 billion year-old granite. A 5 km ramp will connect to an eventual 60 km of tunnels over 4 sq km, housing 6000 copper canisters containing the used fuel. Bentonite clay would surround each canister to adsorb any leakage. The repository concept is known as KBS-3.

SKB applied for a permit to build an encapsulation plant next to CLAB at Oskarshamn in November 2006. This will be operated with CLAB and licensing is expected after 2009. Encapsulated used fuel will make its last journey from here to the repository at Östhammar.

Nuclear generators are responsible for the costs of managing and disposing of spent fuel, and must provide for those costs as they go. They pay a fee set by the government to a state fund administered by SKI to cover waste management and decommissioning. This is based on advice from SKB and has averaged SEK 0.02/kWh (0.21 Euro cents/kWh).

Some 4.8 tons of metal used fuel from the R-1 research reactor has been sent to the UK's Sellafield for reprocessing in the Magnox reprocessing plant, since it cannot safely be stored long-term. Plutonium from this will be combined with the small quantity from reprocessed Oskarshamn fuel (reprocessed some years ago) and returned as MOX fuel.

3.27.3 Decommissioning

Four power reactors – Agesta, Marviken (never operated) and Barsebäck 1 & 2 – are being decommissioned, along with three research reactors – R1, R2 and R2-0 at Studsvik's Nyköping site. R1 has now been dismantled.

3.28 Switzerland

- Switzerland has 5 nuclear reactors generating 40% of its electricity. Two large new units were planned.
- A national vote had confirmed nuclear energy as part of Switzerland's electricity mix.
- However, in June 2011 parliament resolved not to replace any reactors, and hence to phase out nuclear power by 2034.

3.28.1 Fuel cycle

Uranium is procured on world markets, enrichment is provided by a variety of contractors, and fuel fabrication is similarly diverse.

3.28.2 Radioactive waste management

Radioactive waste is mostly handled by Zwilag, a company owned by the four Swiss nuclear utilities. Its ZZL (zentrales Zwischenlager) commenced operation as a central interim dry cask storage facility for high-level wastes in 2001 at Würenlingen. This is adjacent to the Paul Scherrer Institute, near NOK's Beznau nuclear power plant, and not far from two others. The Zwilag site also has facilities for incineration (in a high temperature plasma oven), conditioning and storage of low- and intermediate-level radioactive wastes.

There is no national policy regarding reprocessing or direct disposal of used fuel. However, utilities have been sending used fuel for reprocessing so as to utilize the separated plutonium in MOX fuel.

Reprocessing is undertaken by Areva, at La Hague in France and by BNFL at Sellafield in UK under contract to individual power plant operators. Most used fuel is transported by rail (and shipped to UK). Switzerland remains responsible for the separated high-level wastes which are returned. About 1000 tons of used fuel has been so far sent abroad for reprocessing, but the 2005 Nuclear Energy Act halted this for ten years from mid 2006. Used fuel is now retained at the reactors or sent to Zwilag ZZL for interim above-ground storage, being managed as high-level waste.

The Gosgen plant has limited pool capacity for used fuel storage, so it will operate an on-site independent fuel storage facility which allows cooling before used fuel is sent to Zwilag ZZL.

In 1972 a national co-operative for disposal of radioactive wastes (NAGRA) was set up, involving power plant operators and the federal government.

NAGRA submitted a demonstration of feasibility of disposal report (Entsorgungsnachweis) to the Swiss government in 2002. The report showed that used fuel elements, separated high-level waste and long-lived intermediate-level waste could be safely disposed of in Switzerland. In June 2006, the Federal Council concluded that the legally required demonstration of disposal feasibility for all these had been successfully provided. Meanwhile the 2005 Nuclear Energy Act required the waste management and disposal program to proceed and be reviewed by the federal authorities. Identification of site options for disposal is proceeding under this Act and the Spatial Planning Act with regional participation, and following federal approval the actual site selection in three stages will follow. Target date for repository operation is 2020.

A proposal for a low- and intermediate-level waste repository at Wellenberg was blocked by a cantonal referendum in 1995. A federal working group reviewed the proposal and recommended in 2000 that it proceed, though modified to allow for retrieval. A further cantonal referendum blocked it in 2002. The revised Nuclear Energy Act removes the cantonal veto right, but requires a national referendum.

Low- and intermediate-level waste from the nuclear power plants is processed into a form suitable for disposal either at sites of origin or at Zwilag in Würenlingen. It is packaged into suitable containers and then stored in facilities at the power plants or at Zwilag. Two smaller interim storage sites for these wastes have been operating since 1993: the government's BZL associated with the Paul Scherrer Institute at Würenlingen and Zwibez at Beznau, which also has a storage hall for dry cask storage of spent fuel and high-level wastes.

At the end of 2006, the volume of packaged low- and intermediate-level waste was 6830 cubic meters. Added to this are the high-level waste and used fuel stored at the power plants and at Zwilag ZZL. At the end of 2006, there were eight containers with separated high-level waste from reprocessing and 17 containers with used fuel stored at Zwilag. (A container is around 6 meters high and 2.5 meters diameter.)

Total costs of radioactive waste management are estimated at CHF 11.9 billion. Nuclear plant owners have paid CHF 8.2 billion towards final waste management and now pay into a national waste disposal fund created in 2000, which held CHF 2.76 billion at the end of 2005.

A Decommissioning Fund was established in 1984 and power plant operators pay annual contributions to this. At end of 2005 it held over CHF 1.25 billion, with projected requirement being CHF 1.9 billion.

Both programs are funded under the Nuclear Energy Act by a levy of about CHF 1 cent/kWh on nuclear power production. The two funds held a total of CHF 4.3 billion at the end of 2006.

3.29 Taiwan

- Taiwan has six nuclear power reactors operating, and two advanced reactors are under construction.
- Nuclear power is considerably cheaper than alternatives.

Taiwan imports 99% of its energy, which is vital to the rapidly industrializing economy.

3.29.1 Fuel cycle and waste management

All materials and services are imported, including 850,000 Separative Work Units (SWU) of enrichment.

A low-level radioactive waste storage facility is operated on Lan-Yu Island by Taipower.

Policy for used fuel is direct disposal, though reprocessing is under consideration. Dry storage for Chinshan and Kuosheng will be needed. A geological repository is planned for 2032 operation.

3.30 Ukraine

- Ukraine is heavily dependent on nuclear energy - it has 15 reactors generating about half of its electricity.
- Ukraine receives most of its nuclear services and nuclear fuel from Russia.
- In 2004 Ukraine commissioned two large new reactors. The government plans to maintain nuclear share in electricity production to 2030, which will involve substantial new build.

3.30.1 Radioactive waste management

There is no intention to close the fuel cycle in Ukraine, though the possibility remains under consideration, nor is there a full radioactive waste management strategy. Pending this, storage of used fuel for at least 50 years is the policy.

Used fuel is mostly stored on site though some VVER-440 fuel is again being sent to Russia for reprocessing. At Zaporozhe a long-term dry storage facility for spent fuel has operated since 2001, but other VVER-1000 spent fuel is sent to Russia for storage. A centralized dry storage facility for spent fuel is proposed for construction in the government's new energy strategy, to operate from 2010.

In December 2005, the Ukrainian government signed a US$ 150 million agreement with the US-based Holtec International to implement the Central Spent Fuel Storage Project for Ukraine's VVER reactors, and in April 2007 Energoatom and Holtec signed the contract to proceed with this.

Used fuel from decommissioned RBMK reactors at Chernobyl is stored, and a new dry storage facility is under construction there. In September 2007 Holtec International and the Ukrainian government signed a contract to complete the placement of Chernobyl's used nuclear fuel in dry storage systems (ISF-2). Removing the radioactive fuel from the three undamaged Chernobyl reactors is essential to the start of decommissioning them. Holtec will complete the dry storage project, begun in 1999 by French Framatome, and plans to use as much of the previous work on the project as possible, with the protection of public health and safety as the overriding criteria. The project is estimated to be worth € 200 million (US$ 269 million) over 52 months. There is full endorsement from the Assembly of Donors, who provide funding for Chernobyl remediation and decommissioning.

Holtec also won a tender conducted by the State Specialized Enterprise "Chernobyl NPP" (SSE ChNPP) to develop a storage system design for the "failed" (damaged) used fuel in dry storage ISF-2.

Also at Chernobyl, Nukem has constructed an Industrial Complex for Radwaste Management (ICSRM) which was handed over in April 2009. In this, solid low- and intermediate-level wastes accumulated from the power plant operations and the decommissioning of reactor blocks 1 to 3 is conditioned by incineration, high-force compaction, and cementation, as required and then packaged for disposal. In addition, highly radioactive and long-lived solid waste is sorted out for temporary separate storage. A low-level waste repository has also been built at the Vektor complex 17 km away.

From 2011, high-level wastes from reprocessing Ukrainian fuel will be returned from Russia to Ukraine and will go to the central dry storage facility.

Preliminary investigations have shortlisted sites for a deep geological repository for high- and intermediate-level wastes including all those arising from Chernobyl decommissioning and clean-up.

3.30.2 Decommissioning

Four Chernobyl RBMK-1000 reactors, plus two almost-completed ones, are being decommissioned. Unit 4, which was destroyed in the 1986 accident, is enclosed in a large shelter and a new, more durable containment structure is to be built by 2014.

This shelter project will be funded by the International Chernobyl Shelter Fund facilitated by the European Bank for Reconstruction and Development (EBRD) and is expected to cost about € 1.2 billion, more than half of which has now been pledged. In September 2007 a € 430 million contract was signed with a French-led consortium Novarka to build this new shelter, to enclose both the destroyed Chernobyl-4 reactor and the hastily-built 1986 structure over it. It will be a metal arch 110 meters high and spanning 257 m, which will be built adjacent and then moved into place.

In May 2005, international donors made pledges worth approximately € 150 million towards the new confinement shelter. The largest contribution, worth more than € 130 million, came from the G8 and the EU. Russia contributed to the fund for the first time and other fund members, which include the USA, increased their contributions, with the Ukrainian government pledging some € 15 million. The European Commission has committed € 239.5 million since 1997, making it the main donor.

Units 1-3 are undergoing decommissioning conventionally - the first RBMK units to do so, and work will accelerate when the new dry storage facility for fuel is built (see Waste Management above).

3.31 United Kingdom

- The UK has 18 reactors generating about 18% of its electricity and all but one of these will be retired by 2023.
- The country has full fuel cycle facilities including major reprocessing plants.
- The first of some 19 GWe of new-generation plants are expected to be on line about 2018.

3.31.1 Fuel cycle facilities and materials

From the outset, the UK has been self-sufficient in conversion, enrichment, fuel fabrication, reprocessing and waste treatment (see Appendix 1, Nuclear Development in the United Kingdom on the WNA website). Uranium is imported.

A 6000 t/yr conversion plant is at the Springfields site, which is managed by Westinghouse on a long-term lease from the Nuclear Decommissioning Authority. Early in 2005, Cameco Corporation bought ten years of toll conversion services from 2006, at 5000 tU/yr. Feed is from Cameco's Blind River refinery in Ontario, Canada.

Enrichment is undertaken by Urenco at Capenhurst in a 1.1 million SWU/yr centrifuge plant, the first part of which dates from 1976. Urenco's shares are ultimately held one-third by the UK government, one-third by the Dutch government and one-third by the German utilities RWE and E.ON.

Urenco is planning to build a 7000 t/yr deconversion plant, or Tails Management Facility, at Capenhurst, with operation expected from 2014. It will treat tails from all three European Urenco sites: Capenhurst, Almelo in the Netherlands and Gronau in Germany. Depleted uranium will then be stored in a more chemically stable form as U_3O_8.

Fuel fabrication of AGR and PWR fuel is at Springfields, and other PWR fuel is bought on the open market. Magnox fuel fabrication, also at Springfields, ended in May 2008 after 53 years of production.

Reprocessing activities at Sellafield are undertaken by Sellafield Ltd on behalf of International Nuclear Services, which is owned by the NDA. A 1500 t/yr Magnox reprocessing plant which opened in 1964 is due to close around 2016. The Thermal Oxide Reprocessing Plant (THROP) was commissioned in 1994 and, as of early 2010, had treated about 6000 tons of used fuel for overseas and domestic customers. Of this, 2300 tons was domestic used AGR fuel. A further 6600 tons arising to the end of the AGR operating lifetimes will need to be treated or stored, depending on the outcome of a review of used oxide fuel management strategy. Less than 700 tons of fuel from overseas customers remains to be reprocessed. It appears likely that Thorp will operate to 2020, according the NDA's revised strategy due to be finalized early in 2011.

MOX fuel fabrication for export has been at the Sellafield MOX plant (SMP, see section on Sellafield in Appendix 1, Nuclear Development in the United Kingdom). In 2010, the

NDA and ten Japanese utilities agreed on a plan to refurbish SMP, and this work was being undertaken over three years by Sellafield Ltd, involving a new MOX fuel fabrication line using Areva technology. However, in August 2011 the NDA reassessed the prospects for the plant and decided to close it. About 15 tons of reactor-grade plutonium owned by the Japanese utilities is being held at Sellafield awaiting incorporation into about 270 tons of MOX fuel, but this may now be done in France or Japan. Consideration was being given to building a new MOX plant in the UK to utilize over 100 tons of stored UK plutonium.

Recycling domestic plutonium has not to date been regarded as economic, so separated UK plutonium has been stored indefinitely pending a future decision on its disposition. (MOX fuel costs about five times as much to fabricate as conventional uranium oxide fuel, which doubles the total fuel cost.)

A March 2011 report outlined options for using or otherwise dealing with the UK's civil plutonium. This comprises some 100 tons of separated reactor-grade plutonium and also that in 6000 tons of used AGR fuel from UK reactors - about half as much again if separated. Three of four options involve using the separated plutonium in MOX fuel, the main question is what to do with the AGR fuel - treat as waste, or reprocess at THORP. The report suggests none of the options will be profitable, but some will have more economic and resource benefit than others. In essence, the report shows that it makes sense to produce MOX fuel from the plutonium. The question for the UK is whether it wants to offset this with extra savings and revenues from the potentially expensive return to the full nuclear fuel cycle that would come with a refurbishment of THORP. The public consultation ended in May 2011.

3.31.2 Radioactive wastes

Most UK radioactive wastes are a legacy of the pioneering development of nuclear power, rather than being normal operational wastes arising from electricity generation – though there is a significant amount of these. Until 1982, some low- and intermediate-level wastes were disposed of in deep ocean sites. In 1993, the government accepted an international ban on this.

Solid low-level wastes are disposed of in the 120 ha Low Level Waste Repository (LLWR) at Drigg in Cumbria, near Sellafield, which has operated since 1959. Intermediate-level waste is stored at Sellafield and other source sites pending disposal.

High-level waste (HLW) arising from reprocessing is vitrified and stored at Sellafield, in stainless steel canisters in silos. All HLW is to be stored for 50 years before disposal, to allow cooling.

A consultation on regulations relating to wastes was carried out from March 2010. A Waste Transfer Pricing Methodology consultation document in the light of this was issued by the government in December 2010, setting out how a price will be determined for the transfer to government of new-build higher-activity waste and its disposal in the

UK's planned Geological Disposal Facility (GDF). This includes setting a cap on waste transfer price to provide operators with some price certainty. The cap will be high - perhaps £1100 million per 1350 MWe PWR, which is three times current cost estimates, and the actual price - including contribution to disposal facility - will be set 30 years after the reactor starts operation, not earlier. Operators will need to make credible and secure provision for funding the waste transfer. Used fuel will be priced in £/tU, not p/kWh as earlier proposed, and as common elsewhere.

The NDA has set up a Radioactive Waste Management Directorate (RWMD) to develop plans for a deep geological repository for high- and intermediate-level wastes and evolve into the entity that builds and operates it. The Geological Disposal Facility (GDF) is expected to cost around £12 billion undiscounted from conception, through operation from about 2040, to closure in 2100. Site selection was expected to be in around 2025. The government has invited communities to volunteer to host the GDF, with three expressions received so far, representing two areas of Cumbria: Allerdale and Copeland. The next steps are to undertake a 4-year geological study; surface research lasting ten years; and finally a 15-year period of underground research, construction and commissioning. In these steps the NDA will seek to find an 11-year saving to enable operation from 2029.

The government is planning for the GDF to accommodate waste from new build as well as legacy waste (which includes committed waste from existing operational facilities and those undergoing decommissioning). Operators of new plants would be charged a fixed unit price for disposal of intermediate-level wastes and used fuel in the GDF. See the section on Geological disposal facility in Appendix 1, Nuclear Development in the United Kingdom (on the WNA web site).

3.32 United States

- The USA is the world's largest producer of nuclear power, accounting for more than 30% of worldwide nuclear generation of electricity.
- The country's 104 nuclear reactors produced 799 billion kWh in 2009, over 20% of total electrical output.
- Following a 30-year period in which few new reactors were built, it is expected that 4-6 new units may come on line by 2020, the first of those resulting from 16 license applications to build 24 new nuclear reactors made since mid-2007.
- However, lower gas prices since 2009 have put the economic viability of some of these projects in doubt.
- Government policy changes since the late 1990s have helped pave the way for significant growth in nuclear capacity. Government and industry are working closely on expedited approval for construction and new plant designs.

The USA has 104 nuclear power reactors in 31 states, operated by 30 different power companies. In 2008, the country generated 4,119 billion kWh net of electricity, 49% of it from coal-fired plant, 22% from gas and 6% from hydro. Nuclear achieved a capacity factor of 91.1%, generating 805 billion kWh and accounting for almost 20% of total electricity generated in 2008. Total capacity is 1088 GWe, less than one-tenth of which is nuclear.

Annual electricity demand is projected to increase to 5000 billion kWh in 2030. Annual per capita electricity consumption is currently around 12,400 kWh.

There are 69 pressurized water reactors (PWRs) with combined capacity of about 67 GWe and 35 boiling water reactors (BWRs) with combined capacity of about 34 GWe – for a total capacity of 101,263 MWe (see Nuclear Power in the USA Appendix 1: US Operating Nuclear Reactors on the WNA website).

Almost all the US nuclear generating capacity comes from reactors built between 1967 and 1990. There have been no new construction starts since 1977, largely because for a number of years gas generation was considered more economically attractive and because construction schedules were frequently extended by opposition, compounded by heightened safety fears following the Three Mile Island accident in 1979.

3.32.1 Radioactive waste management policy

From the IAEA NEWMDB country profile page for the USA:

Radioactive waste management policy focuses on disposal of waste in a manner that is protective of human health and the environment. Radioactive wastes in the United States have many designations depending on their hazards and the circumstances and processes creating them. Radioactivity can range from just above background to very high levels, such as parts from inside the reactor vessel in a nuclear power plant. The day-to-day rubbish generated in medical laboratories and hospitals, contaminated by medical radioisotopes, is also designated radioactive waste. High-level waste (HLW) and transuranic (TRU) waste is managed for disposal in a geologic repository. The U.S. is currently developing a new strategy for management and disposal of HLW. Other waste, such as low-level radioactive waste (LLW) and uranium and thorium mill tailings are disposed in near surface or surface disposal facilities. A significant volume of waste in the U.S. results from decommissioning and cleanup of nuclear and radiological facilities. Waste with both radioactive and hazardous constituents in the United States is called “mixed” waste (mixed LLW or mixed TRU waste). Spent fuel is managed as a nuclear material and not as a waste.

3.32.2 Waste management strategy

From the IAEA NEWMDB country profile page for the USA:

Commercial and government facilities exist for low-level radioactive waste (LLW) processing, including treatment, conditioning, and disposal. Generators prepare LLW for shipment to licensed disposal facilities. Class A, B and C LLW is disposed in near surface facilities, i.e., a land disposal facility in which radioactive waste is disposed of in or within the upper 30 meters of the earth’s surface. Greater-Than-Class C LLW is stored until an adequate method of disposal is established

Transuranic waste generally consists of protective clothing, tools, glassware, equipment, soils, and sludge contaminated with manmade radioisotopes beyond or “heavier” than uranium on the periodic table of the elements. These elements include plutonium, neptunium, americium, curium, and californium. TRU waste is produced during nuclear fuel research and development; and during nuclear weapons research, production, and cleanup. TRU waste from the government’s defense activities is disposed in a deep geologic repository, the Waste Isolation Pilot Plant.

High level waste (HLW) from commercial reprocessing activities was vitrified and is stored at the former reprocessing plant in West Valley, New York. Defense HLW is stored, managed and treated at three DOE sites.

Uranium recovery is the extraction or concentration of uranium from any ore processed primarily for its source material content. This results in waste from uranium solution extraction processes. These wastes usually have relatively low concentrations of radioactive materials with long half lives. Uranium recovery facilities shut down or scaled back operations in the early 1980s, when the price of uranium fell. Many of the previously operating facilities were reclaimed or are in the process of remediating (decommissioning) waste resulting from extracting uranium. The product from uranium recovery facilities is processed to enrich the fissile content. Tailings containing depleted uranium are a by-product of the enrichment process. Numerous tailings disposal facilities exist within the U.S.

3.32.3 Conditioning, treatment, and storage facilities

Specific detailed tables and data on commercial and government processing and storage facilities in the United States are given in IAEA U.S. Country Report 2008.

From the IAEA NEWMDB country profile page for the USA:

Radioactive wastes are treated primarily to produce a structurally stable, final waste form and minimize the release of radioactive and hazardous components. The United States does not commonly make a distinction between the terms treatment and conditioning. U.S. terminology covering both conditioning and treatment is generally referred to as treatment or processing.

Commercial generators of LLW waste in the United States must treat these wastes to remove free liquids, and stabilize or destroy other hazardous components contained in the waste. Wastes are also often treated to reduce the final disposal volume through compaction and incineration. Private companies in the United States provide processing (e.g. packaging and treatment) and brokerage services to facilitate safe storage, transportation and, ultimately, disposal of LLW at one of three commercial disposal facilities. Some of these waste processor/brokers serve limited clientele. Others perform these services for a wider body of clients.

DOE has numerous facilities for management of waste at its sites. Many facilities exist to provide lag storage until waste is treated and disposed.

HLW is stored at four sites where it was generated from reprocessing of spent fuel:

- All HLW generated from reprocessing at the former commercial reprocessing plant at West Valley, New York, between 1966 and 1972 was vitrified and is awaiting disposal.
- HLW from reprocessing defense materials at the Savannah River Site consists of both insoluble solid chemicals and water soluble salts. The waste is stored in underground stainless steel tanks until treated. Waste is being transferred to the site’s Defense Waste Processing Facility (DWPF) for immobilization in borosilicate glass.
- Reprocessing defense materials at the Hanford Site began in 1944, and ended nearly 50 years later. The waste is stored in 177 underground tanks. DOE plans to process the tank waste after treatment (vitrification of HLW). Design and construction of the Waste Treatment Plant, which includes a pre-treatment facility, low-activity waste treatment facility, HLW facility, and analytical laboratory is progressing.
- HLW from more than 50 years of defense spent fuel reprocessing at Idaho National Laboratory has been stored in tanks and treated for disposal. Much of the waste was previously treated and is now stored as dry granular calcine in stainless steel bins. The remaining liquid HLW contains a high concentration of sodium, and will be treated by steam reforming.

Residual waste in the tanks at Hanford, Idaho and Savannah River has been managed as HLW. DOE may determine certain quantities of this residual waste from reprocessing are not HLW if certain conditions are met. DOE consults with NRC prior to making such determinations and depending on the location, follows the process set forth in section 3116 of the National Defense Authorization Act (NDAA) for Fiscal Year 2005 or the Waste Incidental to Reprocessing (WIR) provisions of DOE Manual 435.1-1, Radioactive Waste Management.

3.32.4 Disposal facilities

Specific detailed tables and data on commercial and government disposal facilities in the United States are given in IAEA U.S. Country Report 2008.

From the IAEA NEWMDB country profile page for the USA:

WIPP is a geologic repository to dispose, safely and permanently, TRU waste left from the research and production of nuclear weapons. WIPP began operations on March 26, 1999, after more than 20 years of scientific study, public input, and regulatory review.

There are currently three active, licensed commercial LLW disposal sites. A license application for a fourth facility has been issued:

- EnergySolutions/Chem-Nuclear, formerly GTS-Duratek (Barnwell, South Carolina) - As of July 2008, access is limited to LLW generators within three states composing the Atlantic Compact (South Carolina, Connecticut, and New Jersey). Barnwell disposes of Class A, B and C LLW.
- U.S. Ecology (on DOE's Hanford Site near Richland, Washington) - restricted access to only the Northwest and Rocky Mountain Compacts. U.S. Ecology disposes of Class A, B and C LLW.
- EnergySolutions, formerly Envirocare of Utah (Clive, Utah) - accepts Class A LLW and mixed LLW for LLW generators not limited or bound by compact rules. See Section H.1 for additional information.
- A license application was issued in 2009 by the State of Texas for a new commercial LLW disposal site at Waste Control Specialists near Andrews, Texas. The proposed site includes a facility to dispose of LLW for the Texas compact and a facility to dispose of Federal mixed LLW and LLW.

Commercial LLW sites now closed are: Beatty, Nevada (closed 1993); Maxey Flats, Kentucky (closed 1977); Sheffield, Illinois (closed 1978), and West Valley, New York (closed 1975).

DOE operates disposal facilities for LLW at: Hanford, Washington; Idaho Site, Idaho; Los Alamos National Laboratory (LANL), New Mexico; Nevada Test Site, Nevada; and Savannah River Site, South Carolina. DOE also operates LLW disposal facilities for waste from cleanup projects (generally large volumes with low concentrations) at Hanford Site, Idaho Site, and Oak Ridge Reservation in Tennessee.

There are also closed disposal facilities managed by DOE. The Greater Confinement Disposal Facility (boreholes) was used to dispose of certain TRU and other defence waste at the Nevada Test Site until 1989. There are closed burial grounds for LLW used decades ago for disposal of wastes resulting from defense activities, e.g., at Hanford, Oak Ridge, and Savannah River. Hydro-fracture was once used at Oak Ridge, Tennessee, for disposal of waste in slate formations beneath the site. DOE has also closed disposal facilities at Monticello, Utah, Weldon Spring, Missouri, and Fernald, Ohio following completion of site cleanup activities.

There are 61 disposal facilities located throughout the U.S. for uranium and thorium mill tailings. Disposal facilities at most these sites are closed and under long term monitoring. Two commercial by-product material disposal facilities are licensed and operating in the U.S. at Clive, Utah, and Andrews, TX.

3.32.5 Storage of spent fuel

Spent fuel is stored in government and licensed non-government facilities. The overwhelming majority is located in spent fuel pools within nuclear power plants or independent spent fuel storage facilities (ISFSIs), many of which are located at decommissioned or operating nuclear power plant sites. Nearly 20 percent of all commercial spent fuel assemblies were stored in dry casks at ISFSIs as of December 2007.

Reprocessing Facilities: No commercial reprocessing facilities are in operation. The West Valley reprocessing plant which closed in 1972 is being decommissioned

4. Transportation of Nuclear Materials

From the WNA:

- About twenty million consignments of all sizes containing radioactive materials are routinely transported worldwide annually on public roads, railways and ships.
- These use robust and secure containers. At sea, they are generally carried in purpose-built ships.
- Since 1971 there have been more than 20 000 shipments of used fuel and high-level wastes (over 80 000 tons) over many million kilometers.
- There has never been any accident in which a container with highly radioactive material has been breached, or has leaked.

4.1 Transportation of Radioactive Materials in the U.S.

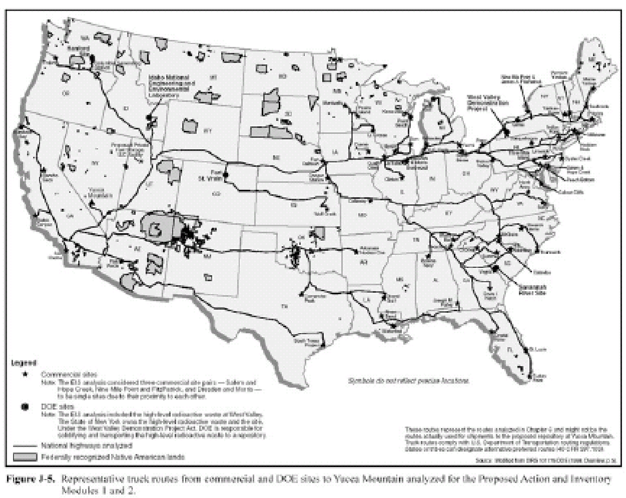
National transportation routes for movement of spent nuclear fuel and high-level radioactive waste in the US were addressed in detail in Appendix J of the Yucca Mountain Final Environmental Impact Statement (FEIS), which accompanied the Site Recommendation (YMP FEIS 2002). DOE later supplemented the FEIS in 2008 to add Nevada transportation data.

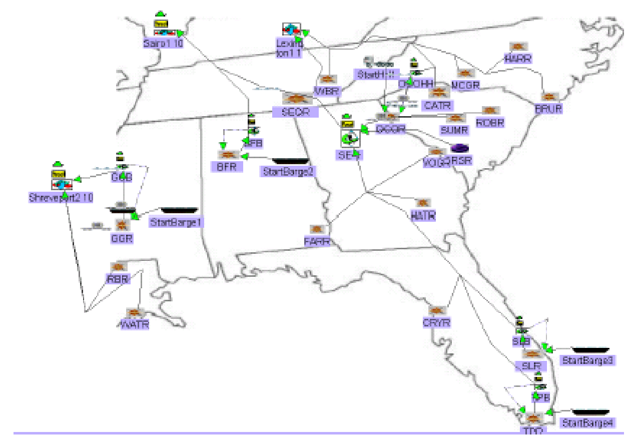
A Total Systems Model (TSM) was prepared based on the 2002 FEIS to interface the waste acceptance, transportation, and repository processes. Christopher Kouts presented a high-level summary of the TSM to the Nuclear Waste Technical Review Board (NWTRB) in November 2005 (Kouts 2005). Figure 2 shows an example map from that presentation of the US rail transportation routes and how they were modeled in TSM.

Figure 2 - Yucca Mountain Total System Model (TSM) Transportation Routes

Key Inputs Example: Transportation Routes

- **Inputs are consistent with the published sources. For example, the national transportation routes are those described in the Yucca Mountain Final Environmental Impact Statement (FEIS).**





FEIS rail transportation routes

TSM rail routes for each region

4.2 International Transportation of Radioactive Materials

4.2.1 Regulation of Transport

Since 1961 the International Atomic Energy Agency (IAEA) has published advisory regulations for the safe transport of radioactive material. These regulations have come to be recognized throughout the world as the uniform basis for both national and international transport safety requirements in this area. Requirements based on the IAEA regulations have been adopted in about 60 countries, as well as by the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), and regional transport organizations.

The IAEA has regularly issued revisions to the transport regulations in order to keep them up to date. The latest set of regulations is published as TS-R-1, Regulations for the Safe Transport of Radioactive Material, 2009 Edition.

The objective of the regulations is to protect people and the environment from the effects of radiation during the transport of radioactive material. Protection is achieved by:

- Containment of radioactive contents;
- Control of external radiation levels;
- Prevention of criticality; and
- Prevention of damage caused by heat.

The fundamental principle applied to the transport of radioactive material is that the protection comes from the design of the package, regardless of how the material is transported.

4.2.2 Types of packaging for nuclear transport

The principal assurance of safety in the transport of nuclear materials is the design of the packaging, which must allow for foreseeable accidents. The consignor bears primary responsibility for this. Many different nuclear materials are transported and the degree of potential hazard from these materials varies considerably. Different packaging standards have been developed according to the potential hazard posed by the material.

'Type A' packages are designed to withstand minor accidents and are used for medium-activity materials such as medical or industrial radioisotopes. Ordinary industrial containers are used for low-activity material such as U_3O_8.
Containers for high-level waste (HLW) and used fuel are robust and very secure and are known as 'Type B' packages. They maintain shielding from gamma and neutron radiation, even under extreme conditions. There are over 150 kinds of Type B packages, and the larger ones cost some US$1.6 million each.

In France alone, there are some 750 shipments each year of Type B packages. This is in relation to 15 million shipments classified as 'dangerous goods', 300,000 of which are radioactive materials of some kind.

Smaller amounts of high-activity materials (including plutonium) transported by aircraft will be in 'Type C' packages, which give even greater protection in all respects than Type B packages in accident scenarios.

4.2.3 Activities Involving Transport of Radioactive Materials

Table 12 shows the variety of fuel cycle activities involving transport of radioactive materials. The WNA website and IAEA discuss each of these transport activities, however, only those activities covering transport of HLW and nuclear fuel assemblies will be covered below.

Table 12 - Activities Involving Transport of Radioactive Materials

From:	To:	Material:	Notes:
Mining	Milling	Ore	Rare: usually on the same site
Milling	Conversion	Uranium oxide concentrate ("Yellowcake")	
Conversion	Enrichment	Uranium hexafluoride (UF_6)	
Enrichment	Fuel fabrication	Enriched UF_6	
Fuel fabrication	Power generation	Fresh (unused) fuel	
Power generation	Used fuel storage	used fuel	After on-site storage
Used fuel storage	Disposal*	used fuel	
Used fuel storage	Reprocessing	used fuel	
Reprocessing	Conversion	Uranium oxide	Called reprocessed uranium
Reprocessing	Fuel fabrication	Plutonium oxide	
Reprocessing	Disposal*	Fission products	Vitrified (incorporated into glass)
All facilities	Storage/disposal	Waste materials	Sometimes on the same site

* Not yet taking place

4.2.4 Transport of used nuclear fuel

When used fuel is unloaded from a nuclear power reactor, it contains: 96% uranium, 1% plutonium and 3% of fission products (from the nuclear reaction) and transuranics). Used fuel will emit high levels of both radiation and heat and so is stored in water pools adjacent to the reactor to allow the initial heat and radiation levels to decrease. Typically, used fuel is stored on site for at least five months before it can be transported, although it may be stored there long-term.

From the reactor site, used fuel is transported by road, rail or sea to either an interim storage site or a reprocessing plant where it will be reprocessed.

Used fuel assemblies are shipped in Type B casks which are shielded with steel, or a combination of steel and lead, and can weigh up to 110 tons when empty. A typical transport cask holds up to 6 tons of used fuel.

Since 1971 there have been some 7000 shipments of used fuel (over 80 000 tons) over many million kilometers with no property damage or personal injury, no breach of containment, and very low dose rate to the personnel involved (e.g. 0.33 mSv/yr per operator at La Hague). This includes 40,000 tons of used fuel shipped to Areva's La Hague reprocessing plant, at least 30,000 tons of mostly UK used fuel shipped to UK's Sellafield reprocessing plant, 7140 t used fuel in 160 shipments from Japan to Europe by sea (see below) and 4500 tons of used fuel shipped around the Swedish coast.

Some 300 sea voyages have been made carrying used nuclear fuel or separated high-level waste over a distance of more than 8 million kilometers. The major company involved has transported over 4000 casks, each of about 100 tons, carrying 8000 tons of used fuel or separated high-level wastes. A quarter of these have been through the Panama Canal.

In Sweden, more than 80 large transport casks are shipped annually to a central interim waste storage facility called CLAB. Each 80 ton cask has steel walls 30 cm thick and holds 17 BWR or 7 PWR fuel assemblies. The used fuel is shipped to CLAB after it has been stored for about a year at the reactor, during which time heat and radioactivity diminish considerably. Some 4500 tons of used fuel had been shipped around the coast to CLAB by the end of 2007.

Shipments of used fuel from Japan to Europe for reprocessing used 94-ton Type B casks, each Shipments of used fuel from Japan to Europe for reprocessing used 94-ton Type B casks, each holding a number of fuel assemblies (e.g. 12 PWR assemblies, total 6 tons, with each cask 6.1 meters long, 2.5 meters diameter, and with 25 cm thick forged steel walls). More than 160 of these shipments took place from1969 to the 1990s, involving more than 4000 casks, and moving several thousand tons of highly radioactive used fuel - 4200t to UK and 2940t to France.

Within Europe, used fuel in casks has often been carried on normal ferries, e.g. across the English Channel.

4.2.5 Transport of vitrified waste

The highly radioactive wastes (especially fission products) created in the nuclear reactor are segregated and recovered during the reprocessing operation. These wastes are incorporated in a glass matrix by a process known as 'vitrification', which stabilises the radioactive material.

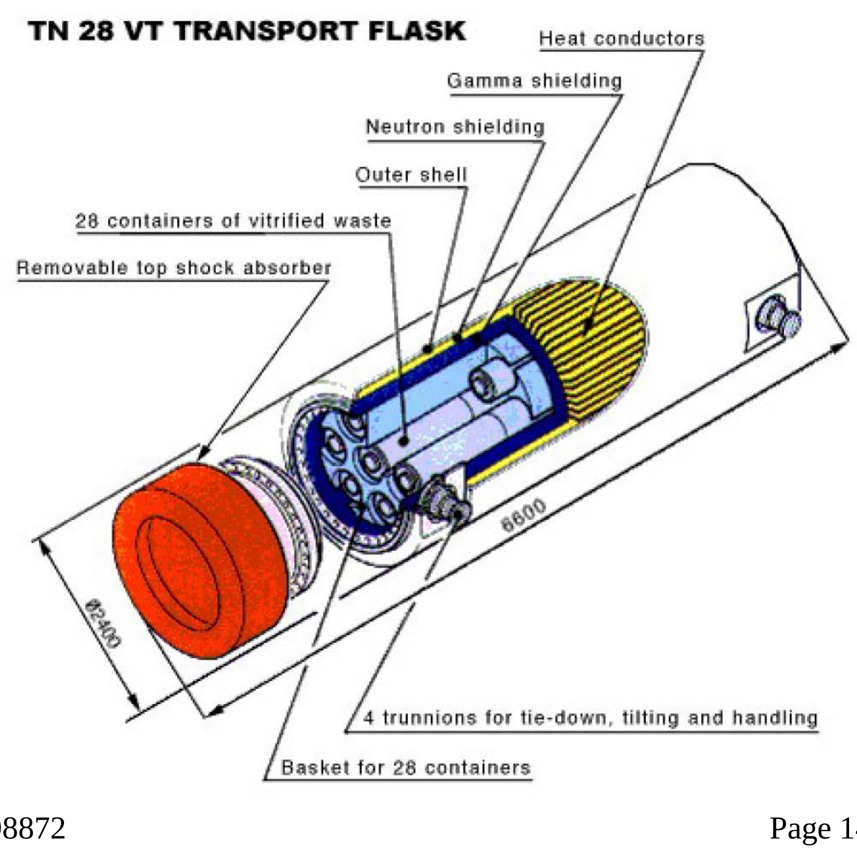
The molten glass is then poured into a stainless steel canister where it cools and solidifies. A lid is welded into place to seal the canister. The canisters are then placed inside a Type B cask, similar to those used for the transport of used fuel.

The quantity per shipment depends upon the capacity of the transport cask. Typically a vitrified waste transport cask contains up to 28 canisters of glass, such as the cask shown in ***Figure 3***.

Return nuclear waste shipments from Europe to Japan since 1995 are of vitrified high-level wastes in stainless steel canisters. Up to 28 canisters (total 14 tons) are packed in each 94-ton steel transport cask, the same as used for irradiated fuel. Over 1995-2007 twelve shipments were made from France of vitrified HLW comprising 1310 canisters containing almost 700 tons of glass.

Return shipments from the UK are due to commence, and there will be about 11 shipments over eight years.

Figure 3 - Example of a Vitrified Waste Transport Cask



4.2.6 Japanese Waste and MOX Shipments from Europe

- From 1969-90 there were more than 160 shipments of used nuclear reactor fuel from Japan to Europe.
- Reprocessing of the Japanese used fuel has been undertaken in UK and France under contract with Japanese utilities.
- Recovered fissile materials are returned to Japan as reactor fuel, notably as mixed oxide (MOX) fuel.
- The first shipment to Japan of immobilized high-level waste from reprocessing took place in 1995 and the 12th and last one from France was in 2007. The first one from UK was in 2010.

A total of ten Japanese electric utilities had contracts with the French company Cogema (now Areva NC) to reprocess their used fuel. These Reprocessing Service Agreements date from 1977-78. Other contracts were with British Nuclear Fuels Limited (BNFL) in UK and are now held by the government's Nuclear Decommissioning Authority. About 40% of the used fuel involved was reprocessed by Cogema/Areva and the rest by BNFL.

From 1969-1990, some 2940 tons of used fuel in total was shipped (in over 160 shipments) by these utilities to France for reprocessing. Shipments of about 4100 tons were to the UK, and by mid 2007 more than 2600 tons of oxide fuel had been reprocessed there, plus a small amount of Japanese Magnox used fuel.

Reprocessing of Japanese used fuel in France finished in 2004 and all the high-level waste from reprocessing the used fuel in France has now been shipped back to Rokkasho in Japan for long-term (30-50 year) storage prior to ultimate disposal. Waste shipments from the UK should be completed by 2016.

Japan has a small (210 tons/yr) reprocessing plant already in operation at Tokai, associated with the Monju fast neutron reactor. A much larger (800 t/yr) reprocessing plant has been built at Rokkasho has been undergoing commissioning activities since March 2006. A 130 t/yr MOX Fuel Fabrication Plant at Rokkasho is under construction and due to enter operation in 2012.

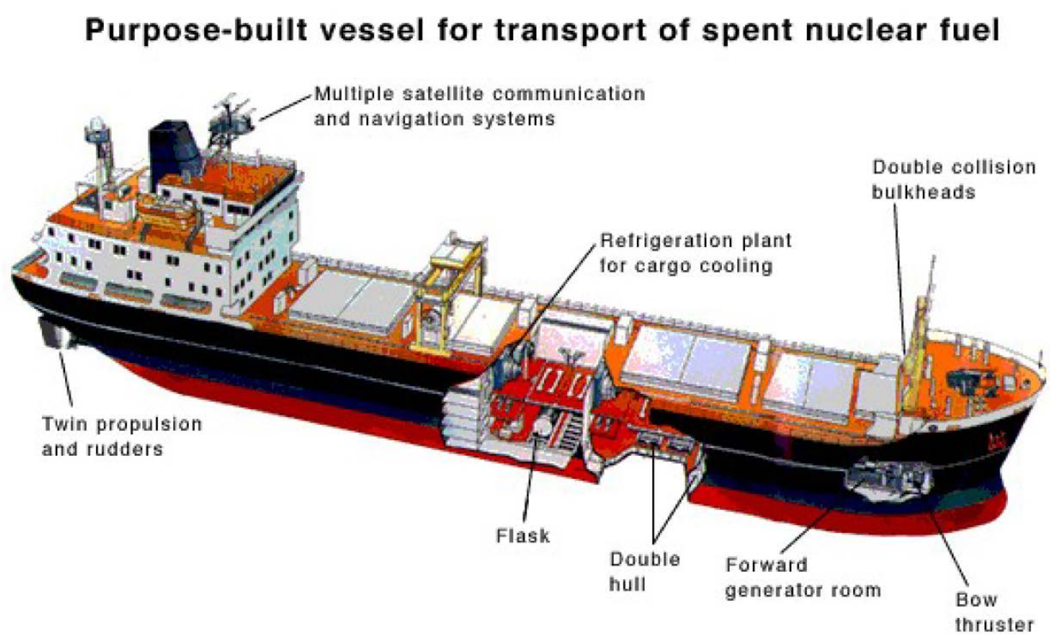
4.2.7 Marine transport

The 500 kg stainless steel canisters containing high-level waste are transported in specially-engineered, heavily shielded steel and resin containers called casks or flasks. Each cask holds up to 28 canisters of vitrified waste and weighs about 130 tons (*Figure **3***). Those used for the high-level waste are very similar to those for transporting the spent fuel from Japan to Europe in the first place, and the MOX fuel on the return voyage.

The ships involved are 104-meter, 5100 ton, specially designed double-hulled vessels used only for the transport of nuclear material (see *Figure **4***). The ships belonging to a British-based company Pacific Nuclear Transport Ltd (PNTL), have been approved for the transport of vitrified residues, and conform to all relevant international safety standards, notably one known as INF-3 (Irradiated Nuclear Fuel class 3) set by the International Maritime Organization. This allows them to carry highly radioactive materials such as high-level wastes, used nuclear fuel, MOX fuel, and plutonium.

They have completed more than 170 shipments and travelled over 8 million kilometers in the 30 years to 2007 without any incident involving a radioactive release. PNTL is now owned by International Nuclear Services Ltd (INS, 62.5%), Japanese utilities (25%) and Areva (12.5%). It is currently renewing its fleet. INS is 51% owned by Sellafield Ltd and 49% by the UK's Nuclear Decommissioning Authority, and managed by Sellafield Ltd.

Figure 4 - Example of a Purpose Built Ship for Nuclear Transport



5. References

EPRI 2010 - Electric Power Research Institute (EPRI 2010) *EPRI Review of Geologic Disposal for Used Fuel and High Level Radioactive Waste, Volume III—Review of National Repository Programs, Final Report, December 2010*

IAEA NEWMDB - International Atomic Energy Agency (IAEA) Net-Enabled Radioactive Waste Management Database (NEWMDB). (http://newmdb.iaea.org); (Web site supported by IAEA member nations).

IAEA PRIS - International Atomic Energy Agency (IAEA) Power Reactor Information System (PRIS). (http://www.iaea.org/programmes/a2/).

IAEA U.S. Country Report 2008 - Country Waste Profile Report for United States of America Reporting year: 2008, published March 2010

Kadak and Yost 2010 – Andrew C. Kadak and Keith Yost, *Key Issues Associated with Interim Storage of Used Nuclear Fuel,* MIT-NFC-TR-123, December 2010

Kouts 2005 – Christopher Kouts, *Systems Integration and Total System Model*, presentation to the NWTRB on November 9, 2005, Las Vegas, Nevada

Kwon et al., 2006 - S. Kwon, W.J. Cho and P.S. Han, *Concept development of an underground research tunnel for validating the Korean reference HLW disposal system,* Tunneling and Underground Space Technology 21 (2006), pp. 203–217.

NAGRA 2002 - National Cooperative for the Disposal of Radioactive Waste (NAGRA) 2002 Project Opalinus Clay: Safety Report. Technical Report 02-05.

National Research Council 2003 - “End Points for Spent Nuclear Fuel and High-Level Radioactive Waste in Russia and the United States”, National Research Council – the National Academies Press ISBN-10: 0-309-08724-2, 2003.

NRC 2011 - Fact Sheet on Decommissioning Nuclear Power Plants, with table of shut down nuclear power plants and ISFIS status information current as of April 2011. (http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html)

NWTRB 2011 - Nuclear Waste Technical Review Board (NWTRB), *Experience Gained From Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries,*

Nuclear News March 2011 - *World List of Nuclear Power Plants*, 13th Annual Reference Issue

Nuclear Engineering International Handbook - *World Nuclear Industry Handbook* - 2003 (later editions are available – 2010 version cited on WNA web site)

Peterson 2003 – Per Peterson, *Nuclear Fuel Cycles*, Public Policy and Nuclear Threats: Training the Next Generation, San Diego, CA July 7, 2003

Whipple 2010 - Chris Whipple presentation to the Blue Ribbon Commission on America's Nuclear Future: Disposal of Spent Nuclear Fuel and High-level Radioactive Waste, Sept. 10, 2010

Witherspoon and Bodvarsson 2006 - "*Geological Challenges in Radioactive Waste Isolation – Fourth Worldwide Review*", P. A. Witherspoon, G. S. Bodvarsson, LBNL-59808, Lawrence Berkeley National Laboratory, Berkeley, CA, April 2006.

World Nuclear Association (WNA) (http://world-nuclear.org), and the WNA public information web site (http://world-nuclear.org/infomap.aspx?=atg).

YMP FEIS 2002 – DOE/EIS-0250 - Yucca Mountain Final Environmental Impact Statement (FEIS), submitted to the NRC with public comments incorporated, February 2002.